Data Sheet
April 1995

AT&T Microelectronics

W2012
1.9 GHz Quadrature Modulator

Features

- Wide supply range: 2.7 V to 5.5 V
- 2 GHz operation
- More than –20 dBm output into 50 Ω load (single-ended)
- Internal 90° phase shifter is accurate over an IF range from 130 MHz to over 350 MHz
- Double-balanced active mixers minimize carrier feedthrough, require low local-oscillator (LO) power
- Automatic power control (APC) capability
- Low current sleep mode

Applications

- Japanese digital cordless (PHP/RCR-28)
- Digital satellite communications
- Multisymbol signaling transmitters
- Personal communications systems

Description

The W2012 is a monolithic integrated circuit that provides indirect, quadrature modulation of an RF carrier by I & Q baseband inputs. The function performed by the W2012 is particularly suited for handheld digital cordless telephones that operate at 1.9 GHz.

The circuit block diagram is shown in Figure 1. From a single local-oscillator input (LO1), the phase shifter produces two LO signals with 90° phase separation and equal amplitude. The LO signals are fed to the in-phase (I) and quadrature (Q) double-balanced mixers. The resulting IF signals are summed and fed into a second mixer where the frequency can be translated to over 2 GHz. Finally, the signal is amplified and fed to a single-ended output which can drive a 50 Ω load.

The ENB/APC input with a logic low allows the device to be put into a powerdown mode, which consumes less than 10 μA of supply current. Above the logic-low threshold of about 0.8 V, the device enters a power control mode which provides a range of output power levels. Full output power is achieved when ENB/APC is about 2 V.

The Pwr Trim input provides an optional means to attenuate the output power. The output power decreases as the resistance between Pwr Trim and ground decreases. A resistance greater than 100 kΩ provides minimum attenuation.

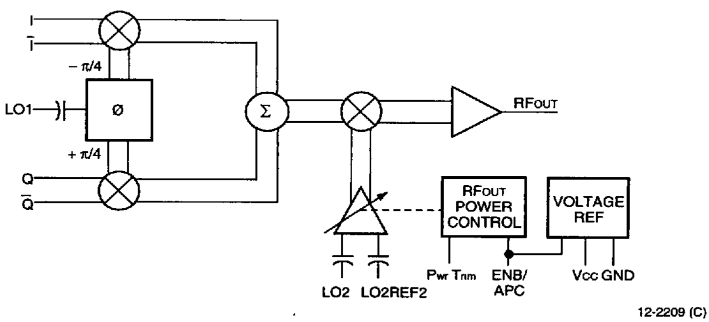


Figure 1. Circuit Block Diagram

0050026 0017723 098

Pin Information

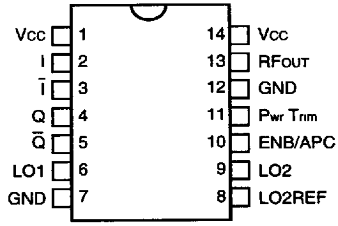


Figure 2. Pin Diagram

Table 1. Pin Description

Pin	Symbol	Name
1, 14	VCC	**Positive Supply Voltage.**
2, 3	I, Ī	**Differential Baseband Inputs.**
4, 5	Q, Q̄	**Differential Baseband Inputs.**
6	LO1	**Local Oscillator.**
7, 12	GND	**dc Ground.**
8, 9	LO2REF, LO2	**Second Local Oscillator Input.**
10	ENB/APC	**Enable/Automatic Power Control.**
11	Pwr Trim	**Power Trim.**
13	RFOUT	**RF Output.**

Absolute Maximum Ratings

Stresses in excess of the Absolute Maximum Ratings can cause permanent damage to the device. These are absolute stress ratings only. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operations sections of the data sheet. Exposure to Absolute Maximum Ratings for extended periods can adversely affect device reliability.

Parameter	Symbol	Min	Max	Unit
Ambient Operating Temperature	T_A	–40	100	°C
Storage Temperature	T_{stg}	–65	150	°C
Lead Temperature (soldering, 10 seconds)	T_L	—	300	°C
Positive Supply Voltage	V_{CC}	—	6.0	Vdc
Power Dissipation	P_D	—	750	mW
Output Current Continuous	I_{OUT}	—	160	mA
Maximum ac Input Voltage Level	—	—	V_{CC}	—
Minimum ac Input Voltage Level	—	Ground	—	—
Enable Input Voltage	V_{ENB}	0	V_{CC}	Vdc

Electrostatic Discharge Caution

This device may be damaged by electrostatic discharge (ESD) over 500 V. Protective measures should be taken during handling.

Operating Ranges

The W2012 provides substantial useful functionality over a wide range of operating conditions. Performance over these ranges may vary for one or more of the parameters specified in the Electrical Characteristics section. Typical performance over a range of conditions is shown in the Characteristic Curves section.

Parameter	Min	Max	Units
Operating Temperature	–30	85	°C
V_{CC}	2.7	5.5	V
f_{LO1} (see Figures 5 and 10)	130	>350	MHz
P_{LO1}	–23	5	dBm/50 Ω
f_{LO2}	100	1800	MHz
P_{LO2}	–23	5	dBm/50 Ω
f_{RF}	<800	>2000	MHz
Maximum Output Power (dependence on f_{RF} and f_{LO1}; see Figure 10)	–15	–5	dBm
External dc Bias Voltage for I & Q Input Pins with 1 Vpp Differential ac Input (see Figure 12)	1.25	V_{CC} – 1.05	Vdc

Electrical Characteristics

Conditions (unless otherwise specified): T_A = 25 °C ± 3 °C, V_{CC} = 3.0 V ± 10%, R_L = 50 Ω, f_{RFOUT} = 1900 MHz, 200 MHz ≤ f_{LO1} ≤ 250 MHz, $f_{LO2} = f_{RFOUT} - f_{LO1}$, $P_{LO1} = P_{LO2}$ = –20 ± 3 dBm, $V_{bias}(I) = V_{bias}(\bar{I}) = V_{bias}(Q) = V_{bias}(\bar{Q})$ = 1.5 Vdc, $I - \bar{I} = 0.50 \cos(2\pi t\ 80\ \text{kHz} + \pi/2)$, $Q - \bar{Q} = 0.5 \cos(2\pi t\ 80\ \text{kHz})$, RF_{OUT} matched to 50 Ω (VSWR < 2:1). See W2012 ac Test Circuit, Figure 3.

Table 2. Electrical Specifications

Parameter	Min	Typ	Max	Unit
V_{CC} Supply Current:				
Active Mode	—	29	35	mA
Sleep Mode	—	—	10	µA
I & Q:				
I and Q Signal Path Bandwidth	—	14	—	MHz
I and Q Baseband Input Resistance (I(Q) to $\bar{I}(\bar{Q})$)	—	200	—	kΩ
I and Q Baseband Input Capacitance (I(Q) to $\bar{I}(\bar{Q})$)	—	1.5	—	pF
I and Q Input Bias Current	—	2.5	—	µA
I and Q Differential Input Signal for Maximum Output	—	1.0	—	Vp-p
LO1				
LO1 Suppression (relative to LO1 input)	—	40	—	dB
LO2				
LO2 Suppression (relative to LO2 input)	—	25	—	dB
Modulation Accuracy: (P_{OUT} = –17 ± 2 dBm)				
Carrier Suppression (relative to wanted sideband)	32	45	—	dB
Lower Sideband Suppression	35	45	—	dB
Transmitted I and Q Amplitude Error	—	±0.1	—	dB
Transmitted I and Q Phase Error	—	±1.0	—	°
Error Vector Magnitude (See page 5.)	—	2.5	5	%
RF Output:				
Output Impedance at 1.9 GHz	—	30 + j50	—	Ω
VSWR Variation (after matching to 1.0:1)	—	1.2	—	—
Output Power Variation over Supply and Temperature (after adjusting P_{OUT} using Pwr Trim)	—	+1, –2	—	dB
Noise Floor @ 1.9 GHz, APC = V_{CC}, Averaging Measurement	—	–144	—	dBm/Hz
Noise Floor @ 1.9 GHz, APC = 1.0 Vdc, Averaging Measurement	—	–138	—	dBm/Hz
ENB/APC:				
VIHMIN (higher voltage turns device on)	—	0.9	1.0	V
VILMAX (lower voltage turns device off)	0.4	0.6	—	V
IILMAX (V_{ENB} = 0.4 V)	—	—	15	µA
IIHMAX (V_{ENB} = 3.0 V)	—	—	200	µA
Powerup/down Time	—	1.0	—	µs
APC Bandwidth	—	7.0	—	MHz
Output Power APC Control Range (from APC = 1.0 Vdc, to APC = 2.0 Vdc; Pwr Trim = no connection)	25	35	—	dB
Pwr Trim:				
Bandwidth	—	1.5	—	MHz
Output Voltage (with 200 kΩ to ground)	—	0.77	—	V
Output Impedance (open emitter + 3 kΩ in series)	—	3k + 0.026/I	—	Ω
Temperature Coefficient of Voltage on Pwr Trim Lead	—	3000	—	ppm/°C
Output Power Dynamic Range using Pwr Trim	35	45	—	dB
External Resistor Value to Trim –17 dBm Output Power	—	14	—	kΩ

Electrical Characteristics (continued)

Test Diagram

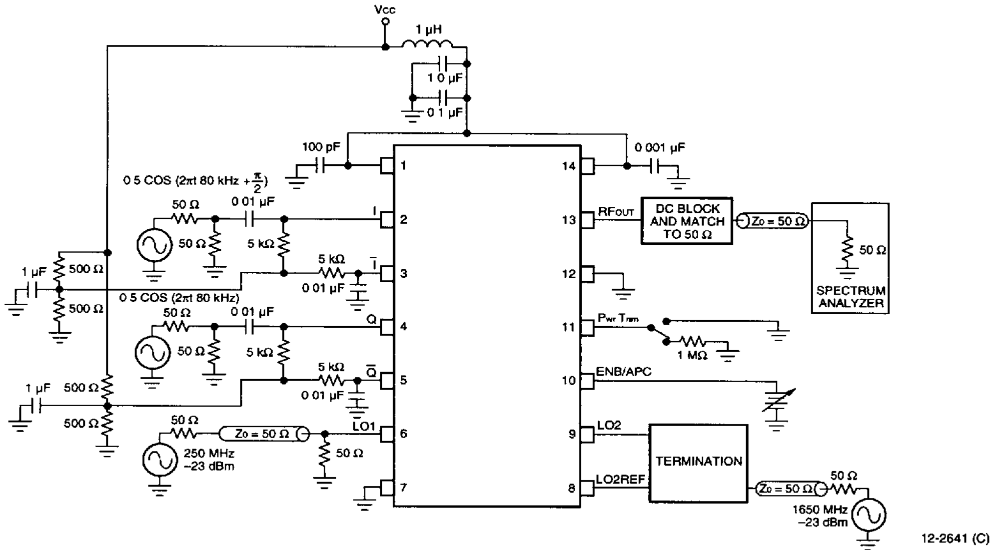
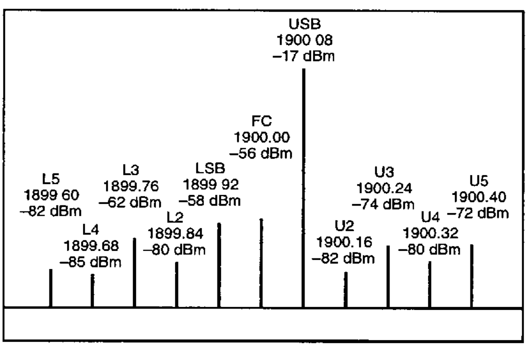


Figure 3. W2012 ac Test Circuit

Error Vector Magnitude (EVM) Testing

Error vector magnitude (EVM) is estimated by feeding signals to the W2012 as described in the Electrical Specifications table (see Table 2). A typical narrow-band, sine wave modulation output spectrum appears in Figure 4.



Note: fB = 80 kHz; fLO1 = 250 MHz; fLO2 = 1650 MHz.

Figure 4. Sine Wave Modulation Output Spectrum

Data from this spectrum is used to estimate EVM by the formula:

$$EVM(\%) = 100[(10^{P(L5)/20} + 10^{P(L4)/20} + 10^{P(L3)/20} + 10^{P(L2)/20} + 10^{P(LSB)/20} + 10^{P(U2)/20} + 10^{P(U3)/20} + 10^{P(U4)/20} + 10^{P(U5)/20})/10^{P(USB)/20}]$$

The hypothetical data presented in Figure 4 would yield:

$$EVM = 100[(79e^{-6}) + (56e^{-6}) + (794e^{-6}) + (100e^{-6}) + (1259e^{-6}) + (79e^{-6}) + (199e^{-6}) + (100e^{-6}) + (251e^{-6})] / (141e^{-3})$$

$$= 2.1\%$$

This approximates worst-case digital modulation results because the sine wave modulation estimate assumes all spurious outputs are in phase, adding their magnitudes as scalars. In addition, this estimate includes full-amplitude measurements of spurious peaks which would appear in adjacent and alternate channels, where a receiver would otherwise provide attenuation. The L3 third-order intermodulation peak and LSB (lower sideband) are normally the unwanted output frequencies which dominate the EVM estimate.

Characteristic Curves

Unless otherwise noted, the following standard conditions apply: standard evaluation board used, Vcc = 3.0 Vdc, room temperature, baseband = 10 kHz at 1.0 Vpp single-ended $\phi(I) = \phi(Q) + \pi/2$, LO1 = 250 MHz at –20 dBm/50 Ω, LO2 = 1650 MHz at –20 dBm/50 Ω, RF = 1.90001 GHz, Vbias (I, $\bar{I}$, Q, $\bar{Q}$) = 1.75 Vdc, R (Pwr Trim) = 200 KΩ, VAPC = 3.0 Vdc.

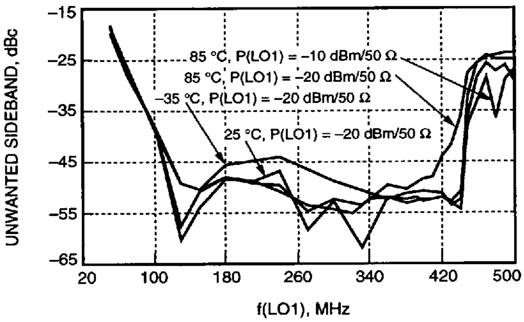


Figure 5. Unwanted Sideband Suppression vs. LO1 Frequency

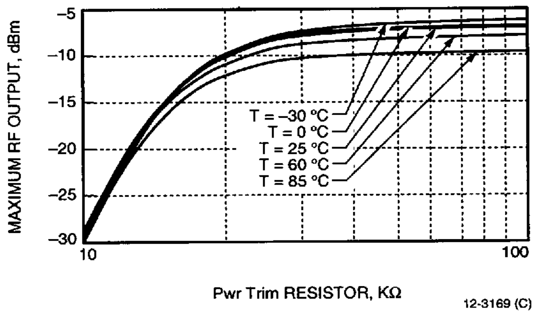


Figure 8. W2012 RF Output Power vs. Pwr Trim Resistor and Temperature (Vapc = Vcc)

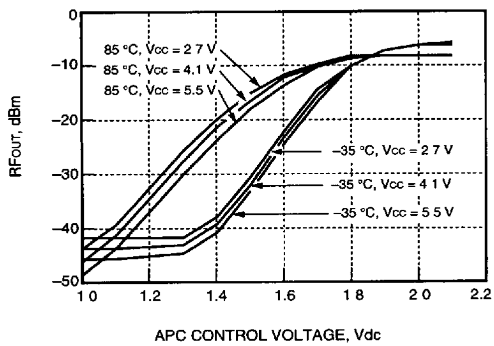


Figure 6. APC Response to Vcc and Temperature

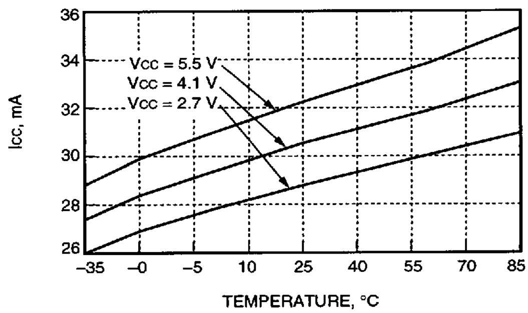


Figure 9. Supply Current vs. Temperature

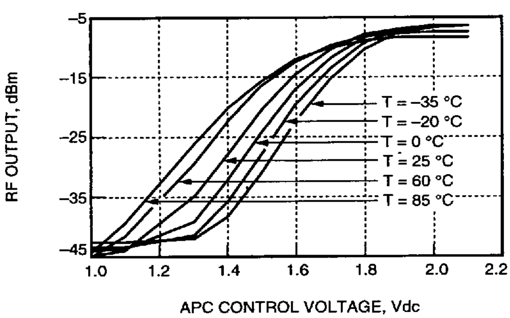


Figure 7. APC Response to Temperature

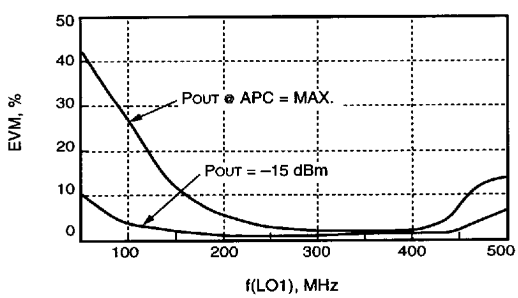


Figure 10. EVM vs. f(LO1)

Characteristic Curves (continued)

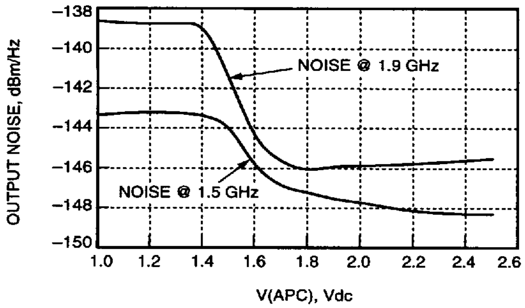


Figure 11. Noise Floor vs. APC Voltage

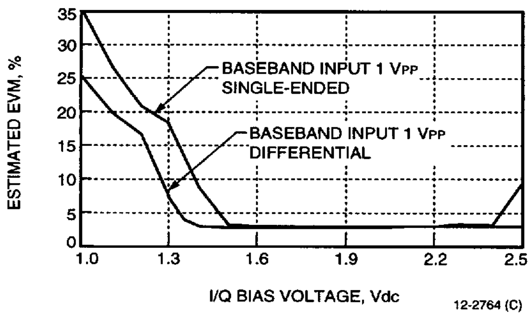


Figure 12. EVM vs. I/Q Bias Voltage

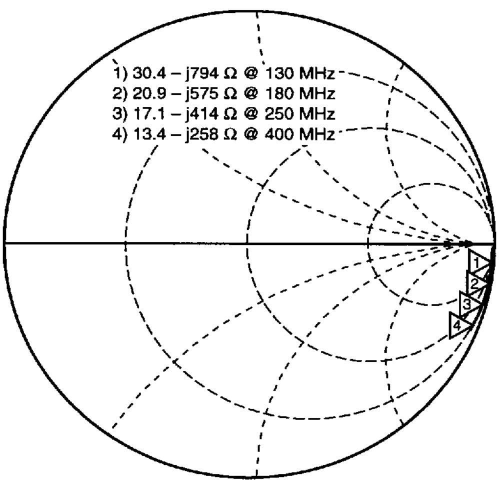


Figure 13. LO1 Input Impedance (50 MHz—500 MHz)

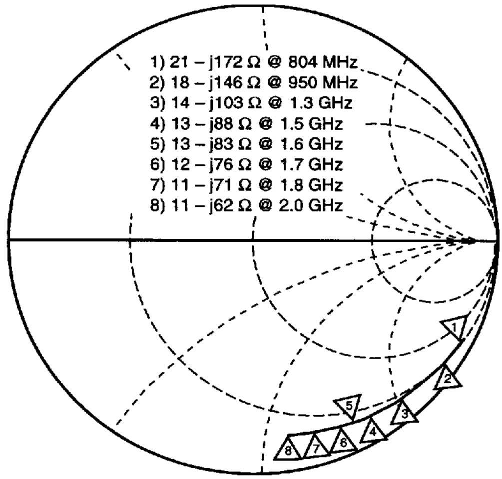


Figure 14. LO2 Input Impedance (800 MHz—2.0 GHz)

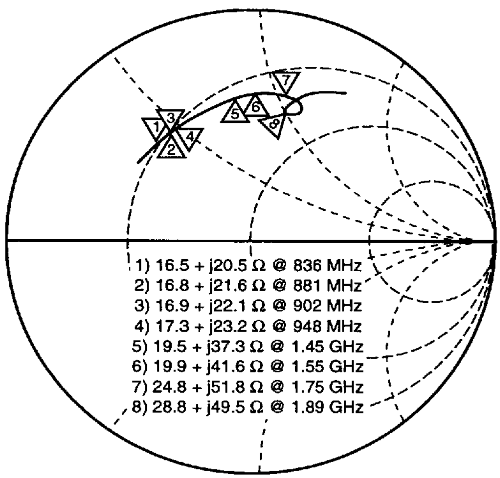
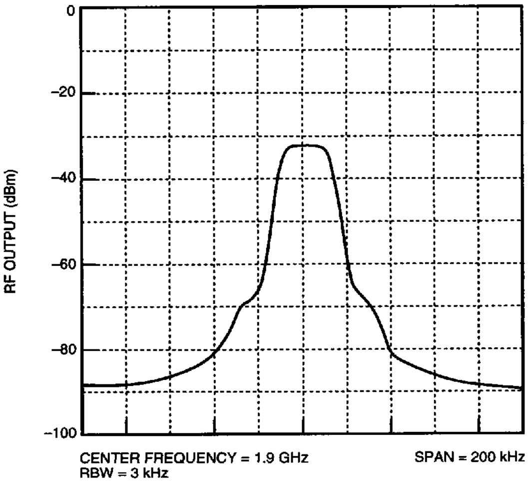


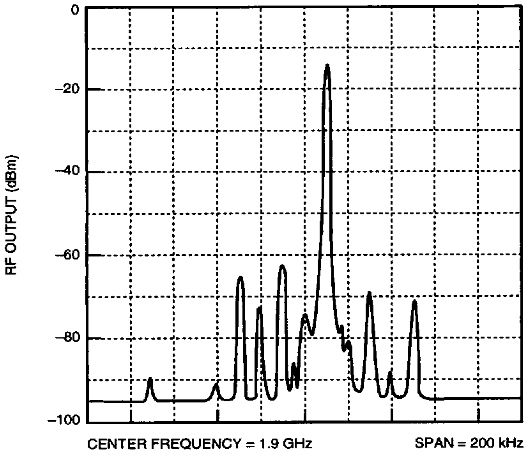
Figure 15. RF Output Impedance (600 MHz—3.0 GHz)

Characteristic Curves (continued)



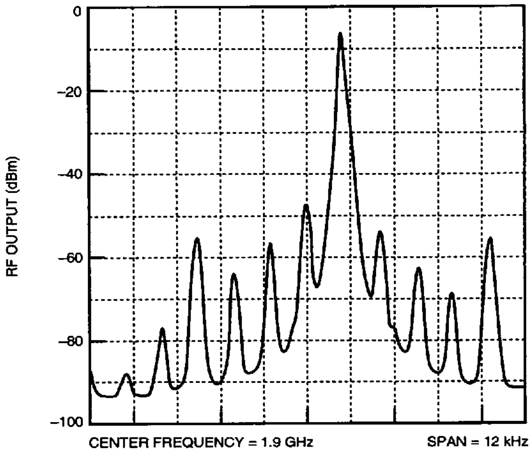
Note: Vcc = 3.0 V; LO1 = 250 MHz @ –20 dBm/50 Ω; LO2 = 1650 MHz @ –20 dBm/50 Ω.

Figure 16. Typical π/4 DQPSK Modulation (α = 0.35) Output Spectrum



Note: Vcc = 3.0 V; LO1 = 250 MHz @ –20 dBm/50 Ω; LO2 = 1650 MHz @ –20 dBm/50 Ω; I, Q = 10 kHz @ 0.5 Vp.

Figure 17. Typical Sine Wave Output Spectrum (USB Set at –15.7 dBm)



Note: Vcc = 3.0 V; LO1 = 250 MHz @ –20 dBm/50 Ω, LO2 = 1650 MHz @ –20 dBm/50 Ω; I, Q = 1 kHz @ 0.5 Vp.

Figure 18. Typical Sine Modulation Output (USB Set at Maximum)

0050026 0017730 228

Application Circuits

Optimum performance of the W2012 is achieved with a circuit as shown in Figure 19. In this case, the LO2 uses a balun to balance the LO2 signal equally between the LO2 and LO2REF inputs. Doing so reduces the amount of LO2 that couples to the output and also reduces the amount of 1.9 GHz signal that gets remixed by feeding into the LO2 input.

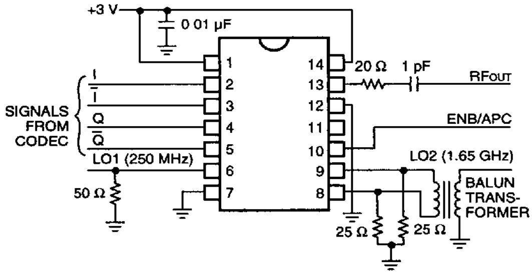


Figure 19. Typical Application with Balun Transformer

If board space permits, a half-wave delay line may be used in place of the balun transformer as in Figure 20.

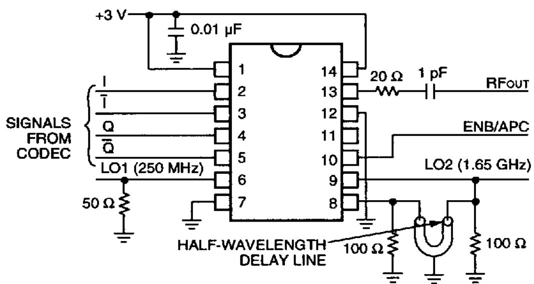


Figure 20. Typical Application with Half-Wavelength Delay Line

Although the performance is not as good (LO2 feed-through is higher), a simpler LO2 input such as that in Figure 21 has also been used.

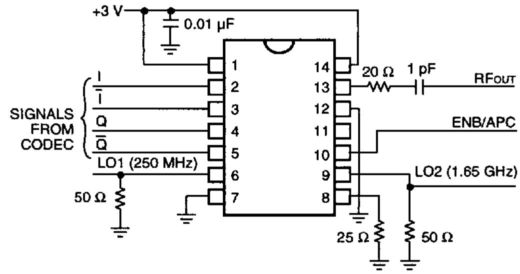


Figure 21. Typical Applications Circuit

Using the W2012

ENB/APC Function

The ENB/APC lead is used to turn the device on and to control the output power. If the voltage on this lead is below 0.6 V, then the device is in a low-current mode. Between 0.95 V and about 2 V, the device draws full supply current and is in a power-control mode. In this region, the output power will vary with the voltage on the ENB/APC lead as shown in Figure 22. Above about 2 V, the device will transmit at full power. For Figure 22, the voltage between I and Ī is 0.5 V and the voltage between Q and Q̄ is 0 V.

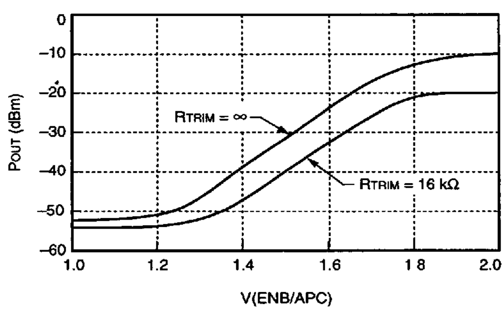


Figure 22. POUT vs. V(ENB/APC)

Using the W2012 (continued)

The relationship between the ENB/APC lead and the supply current and output power is shown in Figure 23.

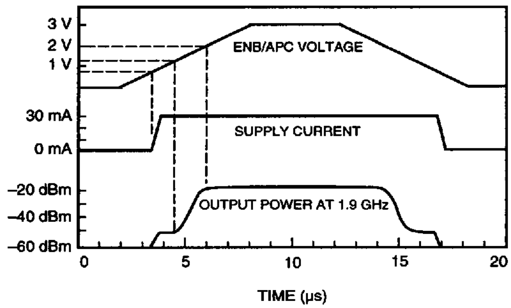
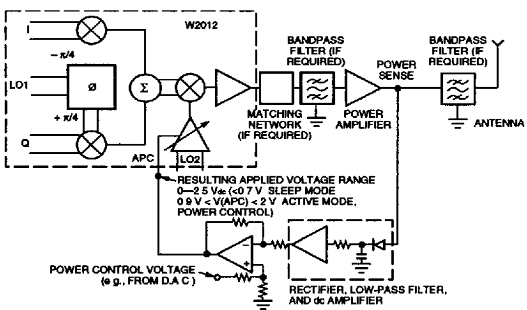


Figure 23. Operation of ENB/APC

It should be noted that the APC function is meant to be used as part of a closed-loop, feedback system. That is, the absolute accuracy of the APC control function has large variation among units. There is additional variation due to temperature; however, when used as part of a closed loop, the APC function allows for accurate setting of the W2012 output power. This is illustrated in Figure 24, where the output power is sampled and converted to a dc voltage proportional to the power. A difference amplifier compares this voltage to a control voltage from a digital-to-analog converter (DAC). The DAC output voltage can be programmed to represent system standard power levels which may be assigned by a base station as part of control protocol.



Note: Using external output power detection and analog feedback components.

Figure 24. Simplified Transmit Power Control Concept

I/Q Input Signal Levels

Figure 25 shows the I/Q inputs biased with 1.7 Vdc and a differential signal of 1 VP-P on both the I and Q inputs (only the connections for pins 2—5 are shown).

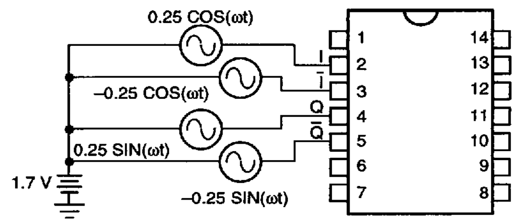


Figure 25. I and Q with Differential Input Signals

Alternatively, the I and Q signals may be single-ended as in Figure 26. Care must be taken not to exceed the input voltage range with low supply voltages.

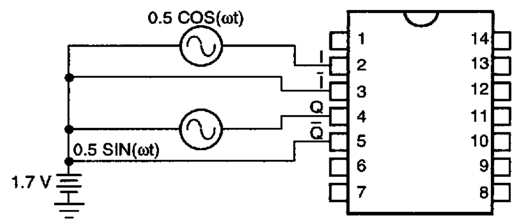


Figure 26. I and Q Single-Ended Input Signals

If only a carrier signal is desired at the output with no modulation, a dc signal may be placed at the input as in Figure 27. (Note that the common-mode level has been changed to keep the pin voltages within the operating range.)

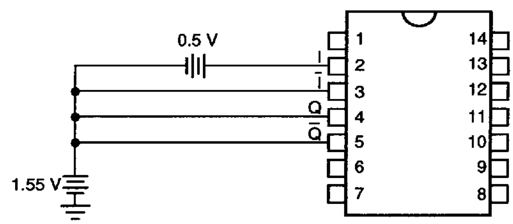


Figure 27. I and Q dc Biased

Power-Trim Function

The Pwr Trim lead provides a way to trim the output power using an external resistor. The intended use is for those applications where a fixed output is desired. Under these conditions, the resistor R_{TRIM} would be set at production time. If the APC lead is used to ramp up and control the output power, then Pwr Trim may be left unconnected or tied to V_{CC}.

As shown in Figure 28, a voltage is established on this lead by an emitter output. This voltage has a strong temperature coefficient in order to maintain a constant output power over temperature. The external resistor is expected to have a zero or small temperature coefficient. An internal 3 kΩ resistor is included for short-circuit protection.

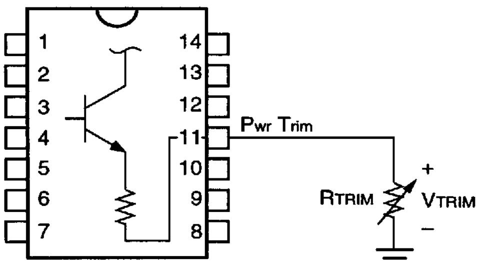


Figure 28. Fixed RF Output Power Using R_{TRIM}

The max power curve in Figure 29 shows how the output power varies as a function of R_{TRIM} with ENB/APC = 3 V. The min power curve in Figure 29 shows how the output power varies as a function of R_{TRIM} with ENB/APC = 1 V.

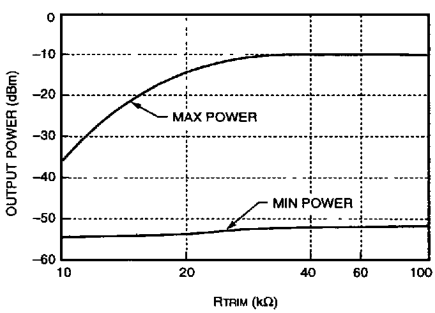


Figure 29. Output Power vs. R_{TRIM}

The output power can also be controlled by the current in the Pwr Trim lead. However, the current will need a strong (about 3000 ppm/°C) positive temperature coefficient to maintain a constant output power over temperature. The graph of output power vs. I_{TRIM} shown in Figure 30 is for a typical device at room temperature.

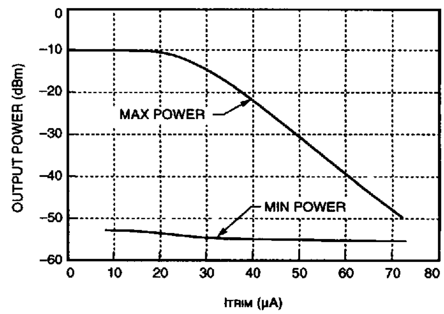


Figure 30. Output Power vs. I_{TRIM}

Third-Order Intermodulation Distortion

An example of third-order intermodulation distortion (IM3) is shown in Figure 31. Two signal tones are at f1 = 1899.9 MHz and f2 = 1900.1 MHz. In addition, carrier feedthrough is shown at 1900 MHz, and two distortion components are shown at 1899.7 MHz and 1900.3 MHz. When two tones at frequencies f_1 and f_2 are transmitted, two IM3 distortion tones at $f_1 - (f_2 - f_1)$ = 1899.7 MHz and $f_2 + (f_2 - f_1)$ = 1900.3 MHz are introduced by the modulator with $I - \overline{I} = 0.50 \cos(2\pi t \times 100\text{ kHz})$ and $Q - \overline{Q} = 0$ V. In Figure 31, the RMS output power is the logarithmic sum of –23 dBm + –23 dBm = –20 dBm. The IM3 distortion is –63 dBm + 23 dBm = –40 dB.

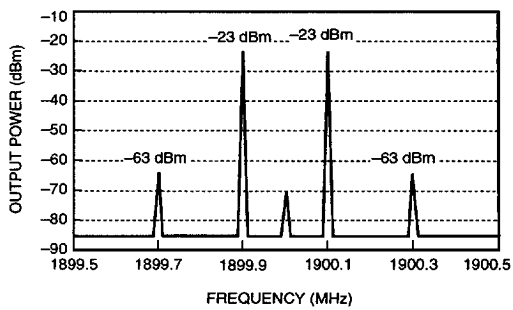
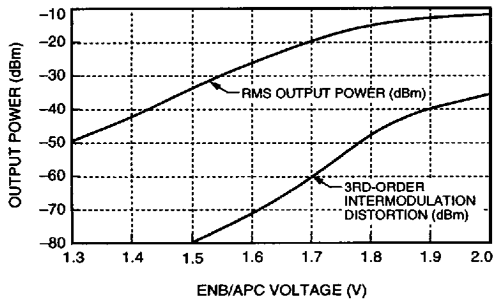


Figure 31. Example of Third-Order Intermodulation Distortion

Third-Order Intermodulation Distortion (continued)

In Figure 32, it is shown how the output power and IM3 vary with the ENB/APC voltage for a typical device. The conditions are the same as in Figure 31.



Note: I = 0.5 cos(ωt); Q = 0 Vac; R_{Trim} = open.

Figure 32. Example of RMS Output Power and Third-Order Intermodulation Distortion as a Function of ENB/APC

Typical Output Spectrum

Figure 33 shows the broadband output spectrum of a typical device. The LO1 frequency was 250 MHz and the LO2 frequency was 1.65 GHz. A differential LO2 signal was used. $I - \bar{I}$ = 0.5 Vdc, $Q - \bar{Q}$ = 0 Vdc. The output power level was adjusted with the ENB/APC lead.

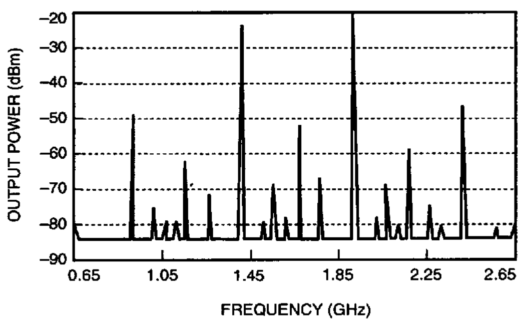


Figure 33. Broadband Output Spectrum of a Typical Device

The data for Figure 33 is shown in Table 3.

Table 3. Values for Output Spectrum

Frequency (GHz)	Power (dBm)
0.65	–79
0.75	–84
0.90	–49
1.00	–75
1.05	–79
1.10	–79
1.15	–62
1.25	–72
1.40	–23
1.50	–79
1.55	–69
1.60	–78
1.65	–53
1.75	–67
1.90	–20
2.00	–78
2.05	–69
2.10	–80
2.15	–59
2.25	–75
2.30	–80
2.40	–46
2.55	–81
2.65	–77

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Evaluation Board Note

The ATTW2012 Evaluation Board is available for customer demonstration (see Ordering Information) of device performance characteristics. The board allows full characterization with RF laboratory bench equipment. Various applications of the device can be demonstrated on the evaluation board.

Outline Diagram

14-Pin SONB

Dimensions are in inches.