

DIL-OEO - Code documentation

Introducing DIL-OEO software

The simulation of a DIL-OEO was written by Etgar C. Levy in MATLAB software. This software is based on the following papers:

1. Etgar C. Levy, Moshe Horowitz, and Curtis R. Menyuk, "Modeling optoelectronic oscillators," J. Opt. Soc. Am. B 26, 148-159 (2009).
2. Etgar C. Levy, Olukayode Okusaga, Moshe Horowitz, Curtis R. Menyuk, Weimin Zhou, and Gary M. Carter, "Theoretical and experimental study of single and dual-loop optoelectronic oscillators," to be published.

The DIL-OEO configuration simulated in this software is shown in figure 1.

The simulation includes the files: DL_OEO.m, Gamp.m, rndnoise.m, filter_8MHz.m, and flicker_noise_FD.m. The simulation is initiated by running the file DL_OEO.m. Before running the software the user should set the input variables which are listed below.

During the simulation the program calls for the files Gamp.m, rndnoise.m, filter_8MHz.m, and flicker_noise_FD.m, which are functions. The file Gamp.m is a function that produces the power gain of the RF amplifier according to the RF power in the input of the RF amplifier. The file rndnoise.m is a function that produces white noise (or random vector) according to a power spectral density function. The distribution of the noise can be set to either complex Gaussian or complex uniform. The flicker_noise_FD.m is a function that produces a flicker noise (a 1/f noise). The function filter_8MHz.m produces the response of the 8 MHz bandwidth filter.

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Block diagram of the dual injection-locked OEO (DIL-OEO)

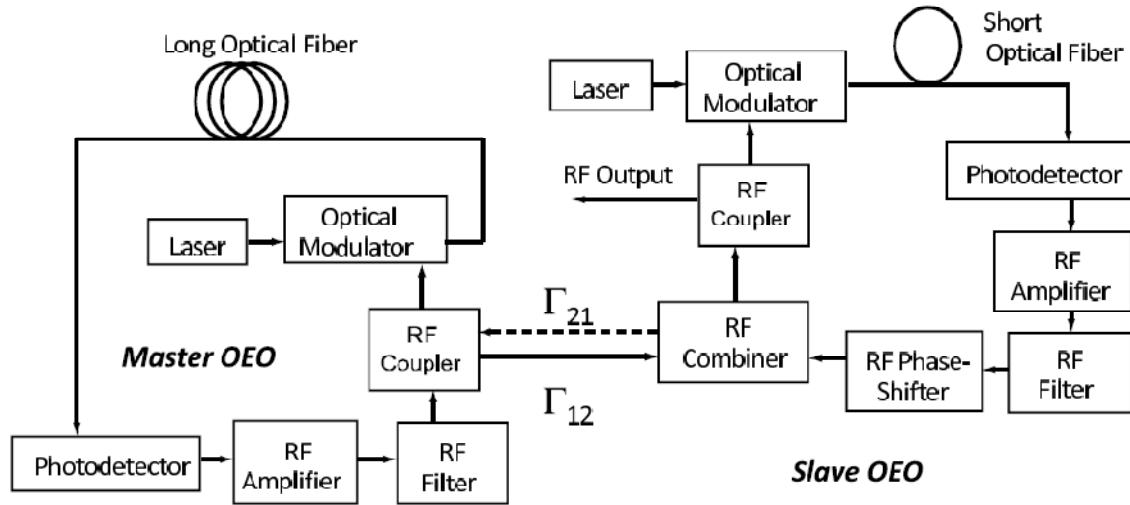


Figure 1. Block diagram of a DIL-OEO

Documentation to the file DL_OEO.m

Inputs and outputs variables to DL_OEO.m

Num	Input	Output
1	N2	vb0_m
2	T2	va0_m
3	DT2	
4	DF2	
5	BW2	
6	t2	
7	freq2	
8	f02	
9	alpha2	
10	P02	
11	VpiAC2	
12	VpiDC2	
13	Vb2	
14	eta2	
15	RFampCorr2	
16	rhoDC2	
17	rho2	
18	R2	
19	CouplerLoss2	
20	Ga2	
21	Gwidth2	
22	Iph2	
23	Vph2	
24	Gs2	
25	noise type2	
26	N12	
27	N1	
28	DT1	
29	T1	
30	DF1	
31	BW1	
32	t1	
33	freq1	
34	f01	
35	alpha1	
36	P01	
37	VpiAC1	
38	VpiDC1	

Num	Input	Output
39	Vb1	
40	eta1	
41	RFampCorr1	
42	rhoDC1	
43	rho1	
44	R1	
45	CouplerLoss1	
46	Ga1	
47	Gwidth1	
48	Iph1	
49	Vph1	
50	Gs1	
51	noise_type1	
52	Kb	
53	Te	
54	qe	
55	NF1	
56	NF2	
57	b_1_1	
58	b_1_2	
59	Nrt	
60	Nmax	
61	x11	
62	x12	
63	x21	
64	x22	
65	x_aa	
66	x_ab	
67	x_ba	
68	x_bb	

List of variables to DL_OEO.m

Parameters of the Slave

num.	name	size	value	meaning
1	N2	1x1	4	single loop discretization
2	T2	1x1	(1.4509*44.1383/3e8)	round-trip time
3	DT2	1x1	T2/N2	time difference
4	DF2	1x1	1/T2	frequency resolution
5	BW2	1x1	1/DT2	Bandwidth [Hz]
6	t2	1xN2	[0:N2-1]*DT2	single loop time-domain vector
7	freq2	1xN2	[-N2/2:N2/2-1]*DF2	single loop frequency-domain vector
8	f02	1x1	round(10e9*T2)/T2	main frequency
9	alpha2	1x1	10^(-8/10)	insertion loss
10	P02	1x1	17e-3	laser's input optical power
11	VpiAC2	1x1	5	The modulator half-wave voltage for AC (V)
12	VpiDC2	1x1	3.15	The modulator half-wave voltage for DC (V)
13	Vb2	1x1	1.81+0.82	modulator's bias voltage (V)
14	eta2	1x1	0.68	η is a parameter determined by the extinction ratio of the modulator $(1+\eta)/(1-\eta)$
15	RFampCorr2	1x1	1	Correction factor to RF amplifier gain
16	rhoDC2	1x1	0.8	photodetector's responsivity at 0 GHz (A/W)
17	rho2	1x1	0.8*10^(-1.62/10)	photodetector's responsivity at 10 GHz (A/W)
18	R2	1x1	50	photodetector's load impedance (Ohm)
19	CouplerLoss2	1x1	10^((-2)/10/2)	Coupler loss
20	Ga2	1x1	10^((60.4)/10/2)	Amplifier's voltage gain
21	Gwidth2	1x1	8e6	Amplifier's bandwidth (Hz)
22	Iph2	1x1	alpha2*P02*rho2/2	Photocurrent (A)
23	Vph2	1x1	Iph2*R2*Ga2	Photovoltage (V)
24	Gs2	1x1	-eta2*pi*Vph2 /VpiAC2*cos(pi*Vb2/VpiDC2)	small signal open-loop gain
25	noise_type2	1x1	'gaussian'	
26	vb0	1xN2		It is used both for the output amplifier and output filter.
27	vb_N12	1xN1		The output voltage of the slave OEO (in the last N12 loops)
28	vb1	1xN2		Used for filter implementation.
29	vb0_m	N2x Nmax		This matrix save the RF output starting from the steady state (Nrt-Nmax). The numbers of columns are the number of cycles in the OEO after the steady-state and the numbers of rows are the number of points during the round-trip.
30	PB4AMP2	1x1	mean(abs(vb0).^2/2/R2)	Average power.

Parameters of the Master

num.	name	size	value	meaning
1	N12	1x1	94	Every N12 round-trips in the slave the master OEO affects
2	N1	1x1	N2*N12	single loop discretization
3	DT1	1x1	DT2	time difference
4	T1	1x1	DT1*N1	round-trip time
5	DF1	1x1	1/T1	frequency resolution
6	BW1	1x1	1/DT1	Bandwidth [Hz]
7	t1	1xN1	[0:N1-1]*DT1	single loop time-domain vector
8	freq1	1xN1	[-N1/2:N1/2-1]*DF1	single loop frequency-domain vector
9	f01	1x1	round(10e9*T1)/T1	main frequency
10	alpha1	1x1	10^(-8/10)	insertion loss
11	P01	1x1	17e-3	laser's input optical power
12	VpiAC1	1x1	5	The modulator half-wave voltage for AC (V)
13	VpiDC1	1x1	3.15	The modulator half-wave voltage for DC (V)
14	Vb1	1x1	1.81+0.82	modulator's bias voltage (V)
15	eta1	1x1	0.68	η is a parameter determined by the extinction ratio of the modulator $(1+\eta)/(1-\eta)$
16	RFampCorr1	1x1	1	Correction factor to RF amplifier gain
17	rhoDC1	1x1	0.8	photodetector's responsivity at 0 GHz (A/W)
18	rho1	1x1	0.8*10^(-1.62/10)	photodetector's responsivity at 10 GHz (A/W)
19	R1	1x1	50	photodetector's load impedance (Ohm)
20	CouplerLoss1	1x1	10^((-2)/10/2)	Coupler loss
21	Ga1	1x1	10^((60.4)/10/2)	Amplifier's voltage gain
22	Gwidth1	1x1	8e6	Amplifier's bandwidth (Hz)
23	Iph1	1x1	alpha1*P01*rho1/2	Photocurrent (A)
24	Vph1	1x1	Iph1*R1*Ga1	Photovoltage (V)
25	Gs1	1x1	-eta1*pi*Vph1 /VpiAC1*cos(pi*Vb1/VpiDC1)	small signal open-loop gain
26	noise_type1	1x1	'gaussian'	
27	va0	1xN1		It is used both for the output amplifier and output filter.
28	va1	1xN1		Used for filter implementation.
29	va0_m	N1x Nmax/ N12		This matrix save the RF output starting from the steady state (Nrt-Nmax). The numbers of columns are the number of cycles in the OEO after the steady-state and the numbers of rows are the number of points during the round-trip.
30	PB4AMP1	1x1	mean(abs(va0).^2/2/R1)	Average power.

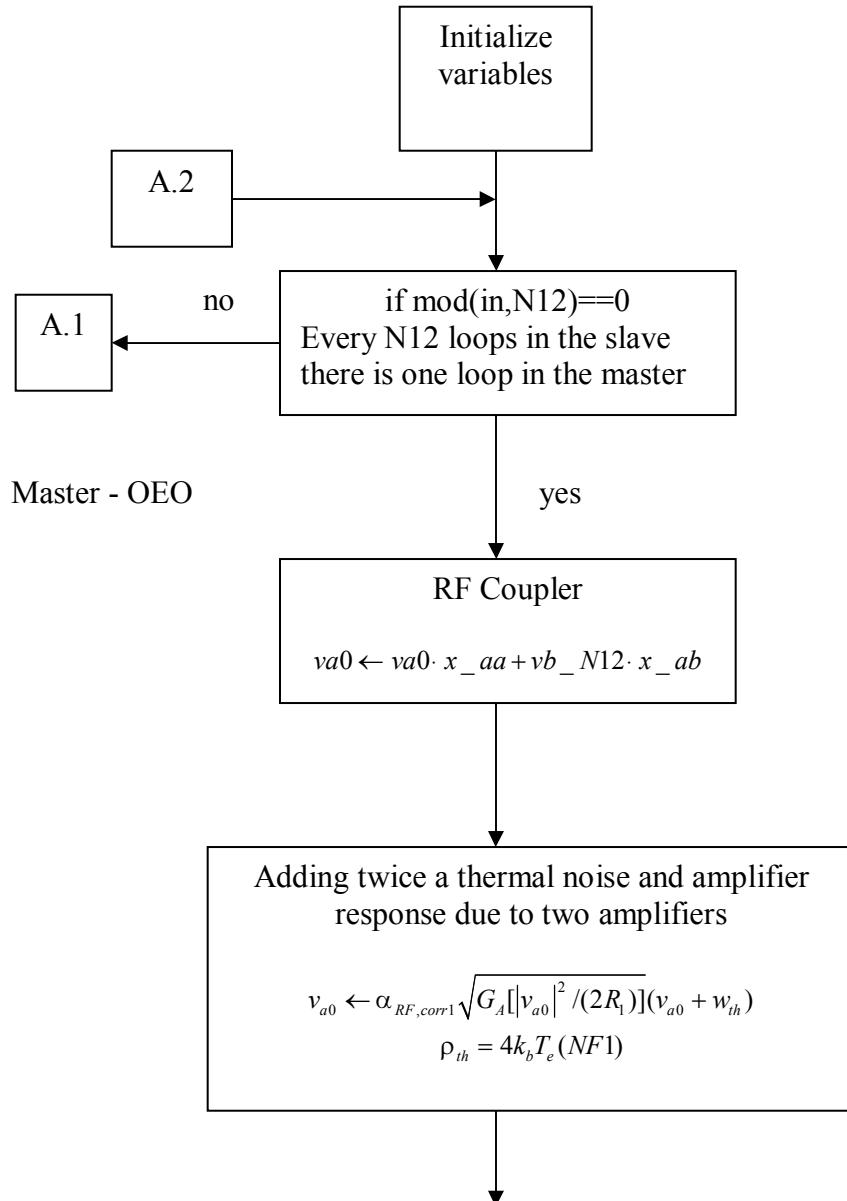
Parameters of the noise

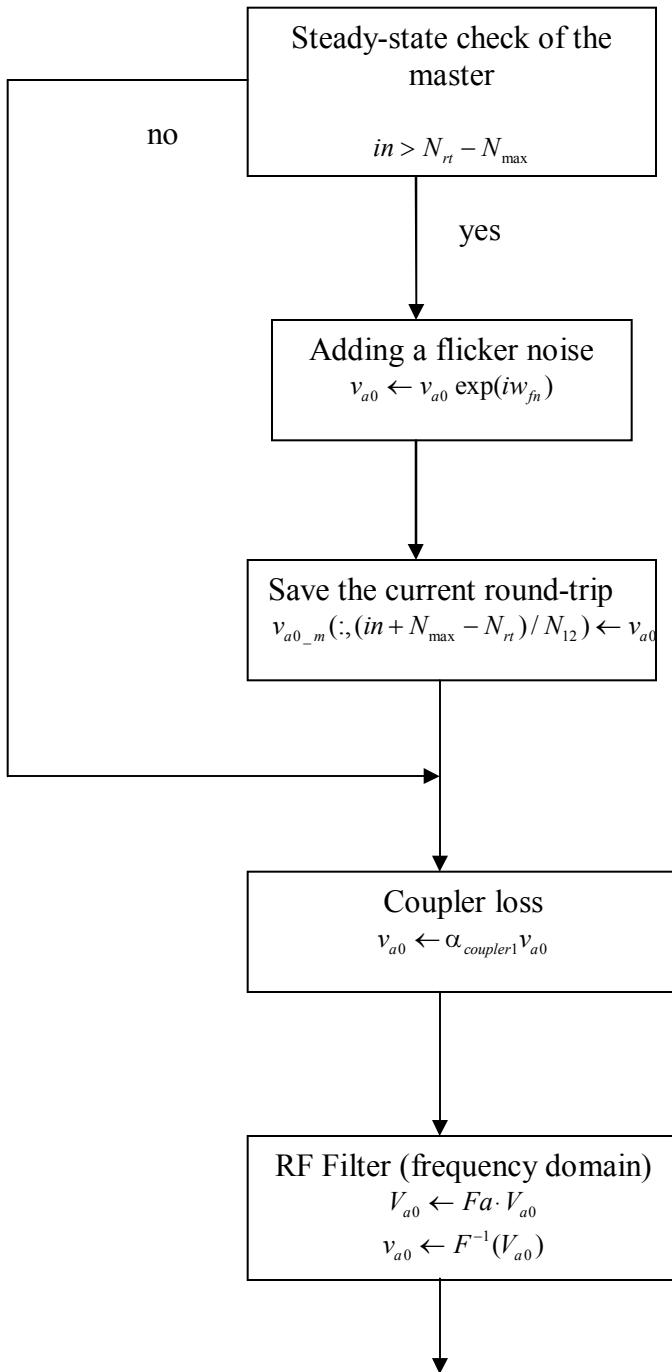
num.	name	size	value	meaning
1	Kb	1x1	1.38e-23	Boltzman constant (J/K)
2	Te	1x1	300	Room temperature (300 K)
3	qe	1x1	1.6e-19	The electron charge (C)
4	NF1	1x1	4	Noise factor
5	NF2	1x1	4	Noise factor
6	rho_THERM1	1x1	4*Kb*Te*NF1	Thermal noise spectral density (W/Hz) – master
7	rho_THERM2	1x1	4*Kb*Te*NF2	Thermal noise spectral density (W/Hz) – slave
8	N_FN1	1x1	Nmax/N12*N1	The total number of saved points - master
9	b_1_1	1x1	30e-12	Parameter of the flicker noise - master
10	dbc_per_hz1	1x1	10*log10(b_1_1/f0)	Parameter of the flicker noise (dBc/Hz) - master
11	flicker_noise_v1	1xN_FN1		Flicker noise vector - master
12	pn1	1xN_FN1	exp(i*flicker_noise_v1)	Flicker noise coefficient
13	b_1_2	1x1	1.8e-12	Parameter of the flicker noise - slave
14	N_FN2	1x1	Nmax*N2	The total number of saved points - slave
15	dbc_per_hz2	1x1	10*log10(b_1_2/f0)	Parameter of the flicker noise (dBc/Hz) – slave
16	flicker_noise_v2	1xN_FN2		Flicker noise vector - slave
17	pn2	1xN_FN2	exp(i*flicker_noise_v1)	Flicker noise coefficient

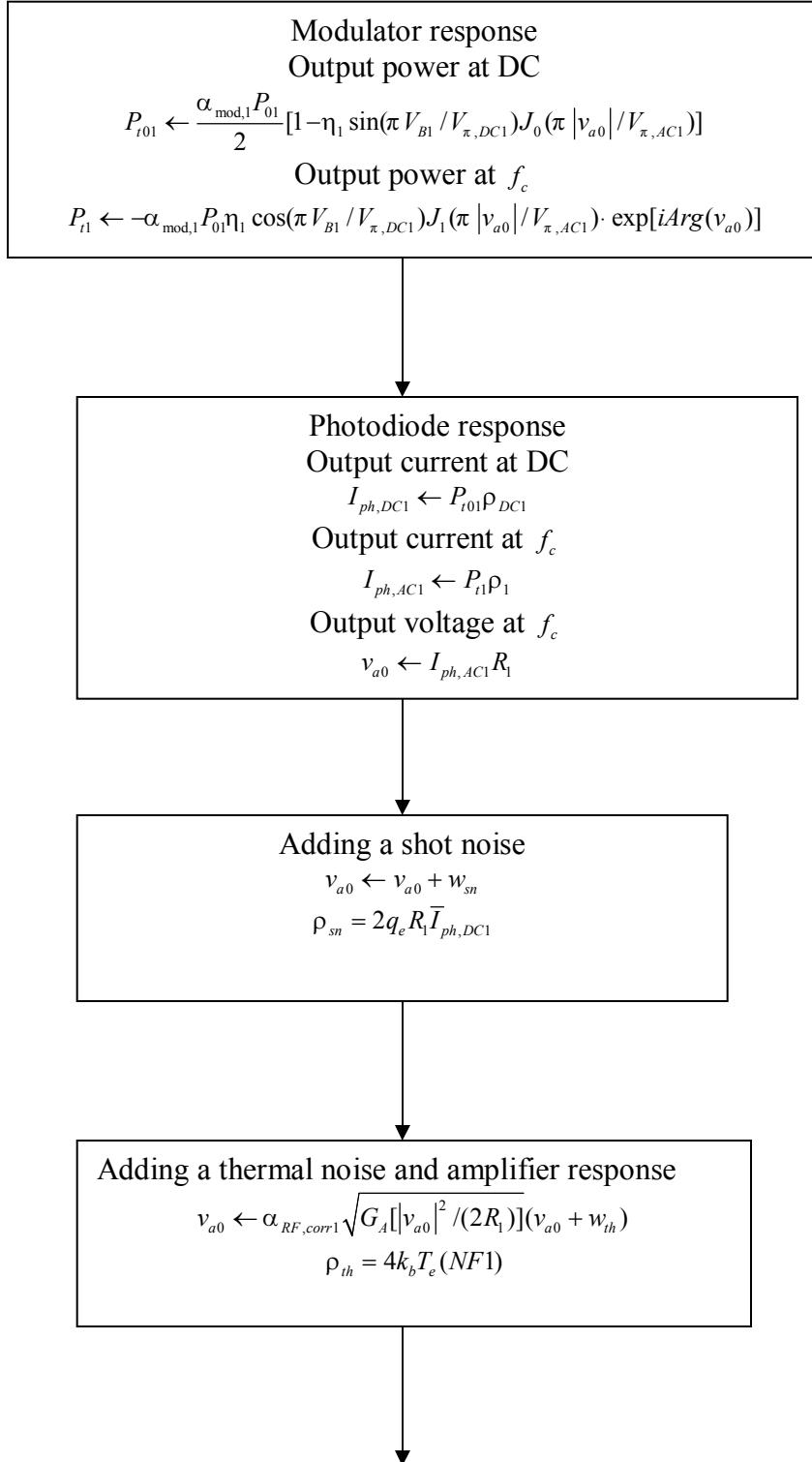
General parameters

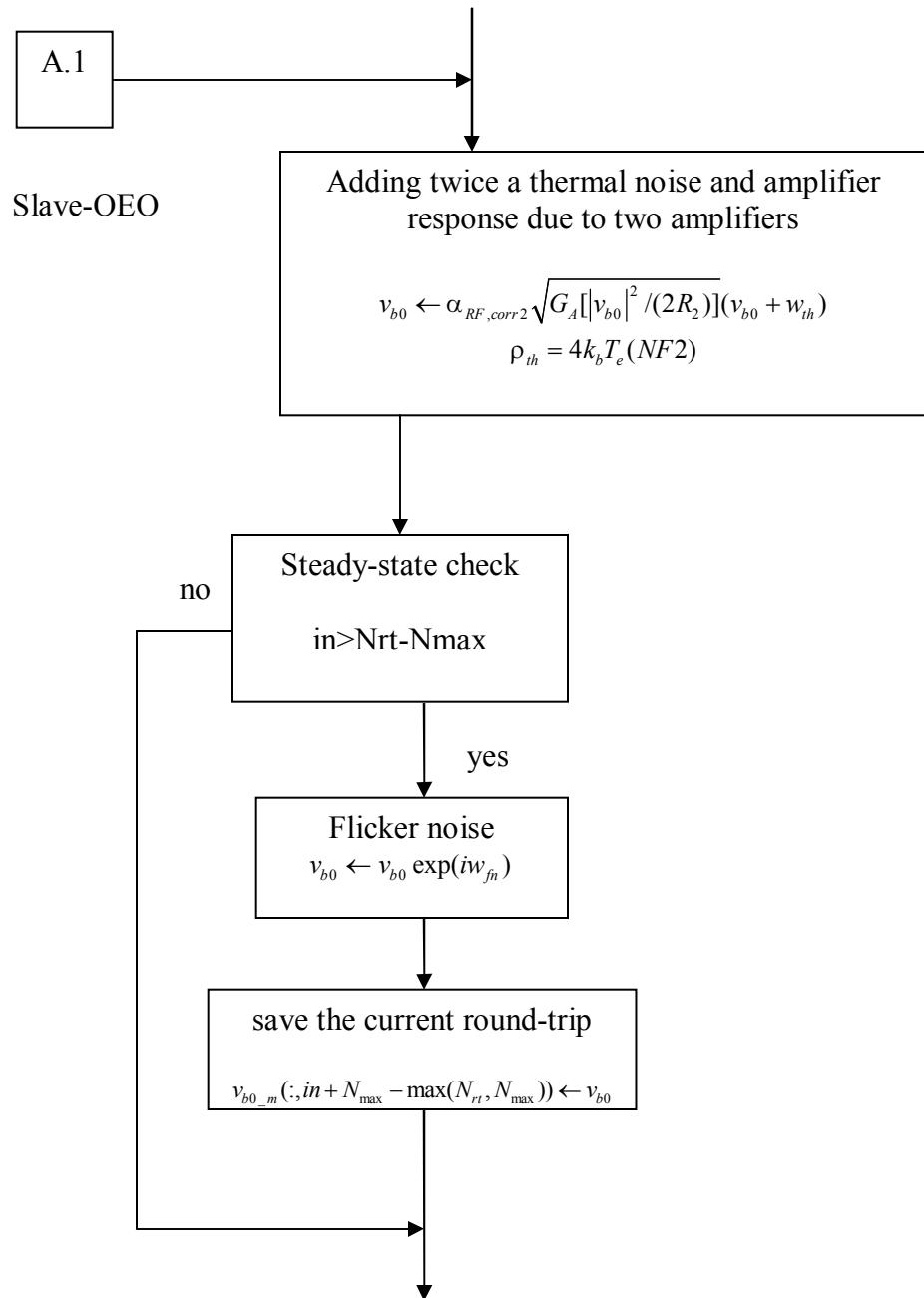
num.	name	size	value	meaning
1	Nrt	1x1	N12*520	The number of cycles in the DL_OEO
2	Nmax	1x1	N12*500	The last number of cycles that are in steady-state. (The number of iterations to reach a steady state is Nrt-Nmax)
3	x11	1x1		??
4	x12	1x1		??
5	x21	1x1		??
6	x22	1x1		??
7	x_aa	1x1		injection voltage coefficient $ x_{aa} ^2 = \Gamma_{11}$
8	x_ab	1x1		injection voltage coefficient $ x_{ab} ^2 = \Gamma_{12}$
9	x_ba	1x1		injection voltage coefficient $ x_{ba} ^2 = \Gamma_{21}$
10	x_bb	1x1		injection voltage coefficient $ x_{bb} ^2 = \Gamma_{22}$
11	N2_2	1x1	2*N2	Number of points that is used in the slave filter
12	DF2_2	1x1	DF2/2	The frequency step-sized that is used in the slave filter
13	freq2_2	1xN2_2	[-N2_2/2:N2_2-1]*DF2_2	The frequency vector that is used in the slave filter
14	Fb2	1xN2_2		filter response to the slave
15	Fa	1xN1		filter response to the master

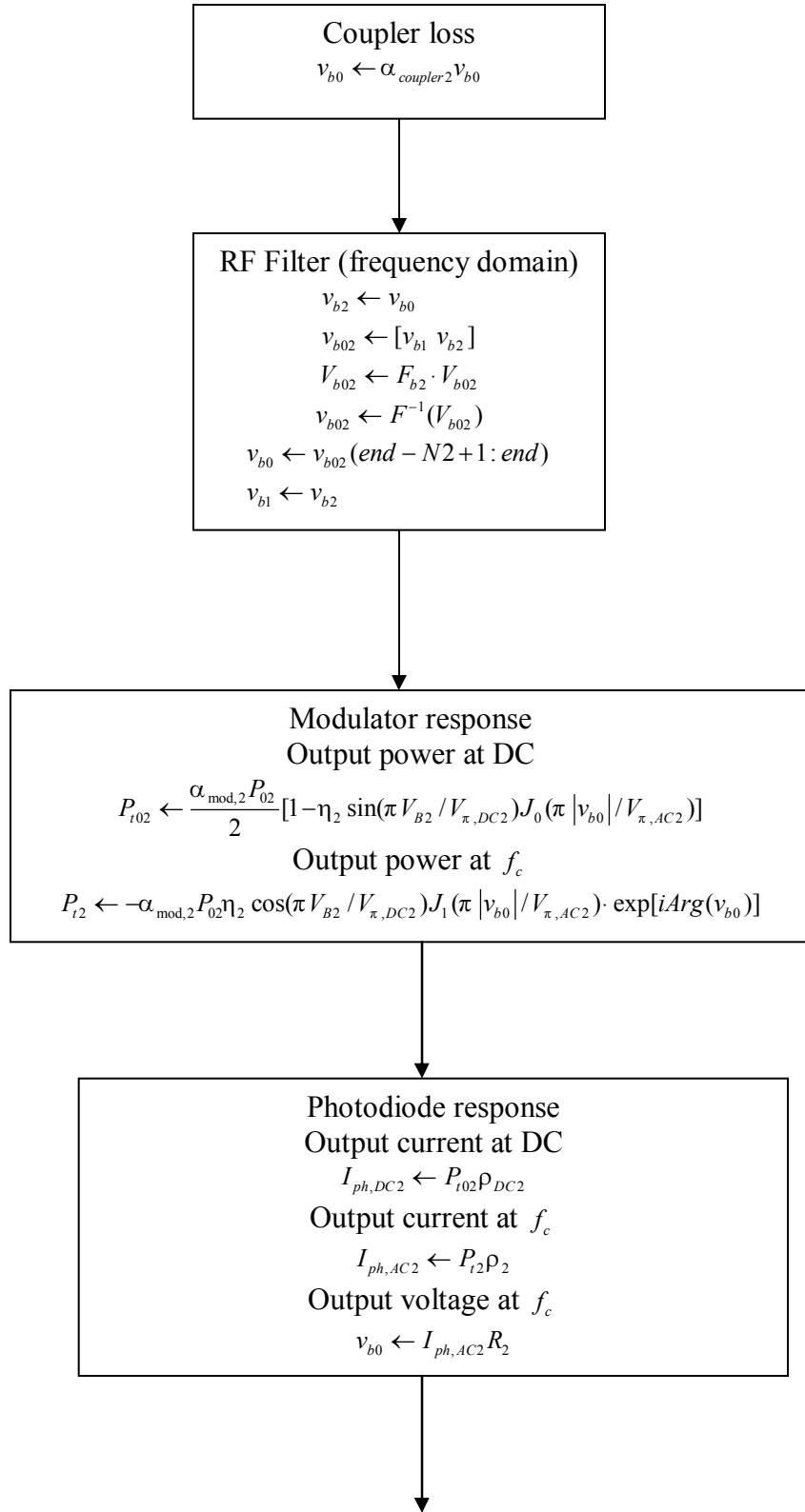
Flow chart of the file DL_OEO.m

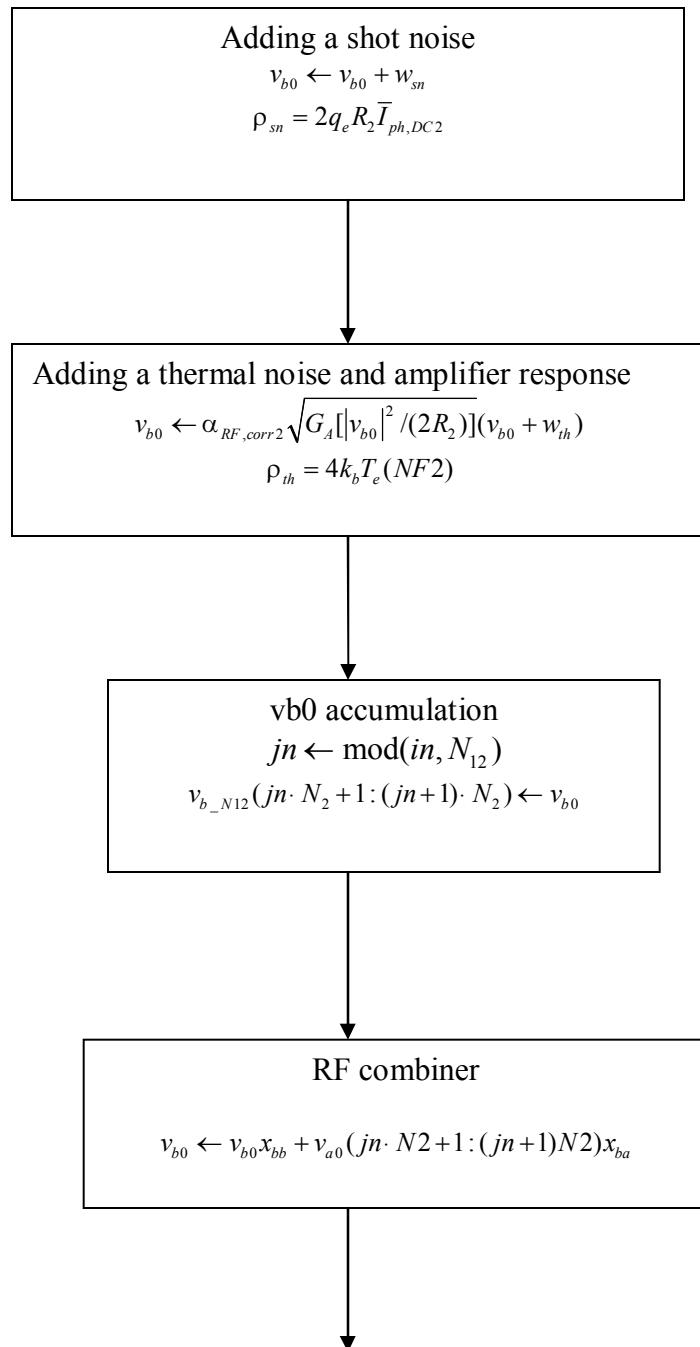


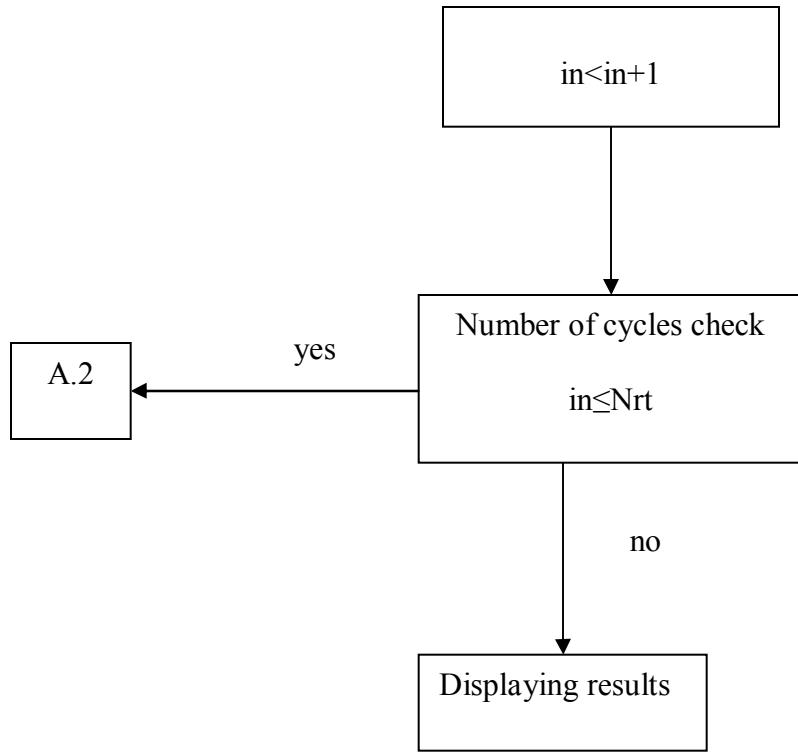












Documentation to the file Gamp.m

Inputs and outputs variables to Gamp.m

Num	Input	Output
1	Pin	G

List of variables to Gamp.m

num	name	size	value	meaning
1	GainSat1	1x33		Measured input power (dBm)
2	GainSat2	1x33		Measure output power (dBm)
3	in0	1x1	7	
4	GsdB	1x1	GainSat2(in0)- GainSat1(in0)	
5	PoutsimdB	1x10		Output power (dBm)
6	PindB	1x10	$10 * \log_{10}(Pin/1e-3)$	Input power (dBm)
7	Poutsim	1x10	$10.^{(PoutsimdB/10)*1e-3}$	Output power (Watt)
8	G	1x10	$Poutsim./Pin$	Power gain of the amplifier
9	Pin	1x10		Input power (Watt)

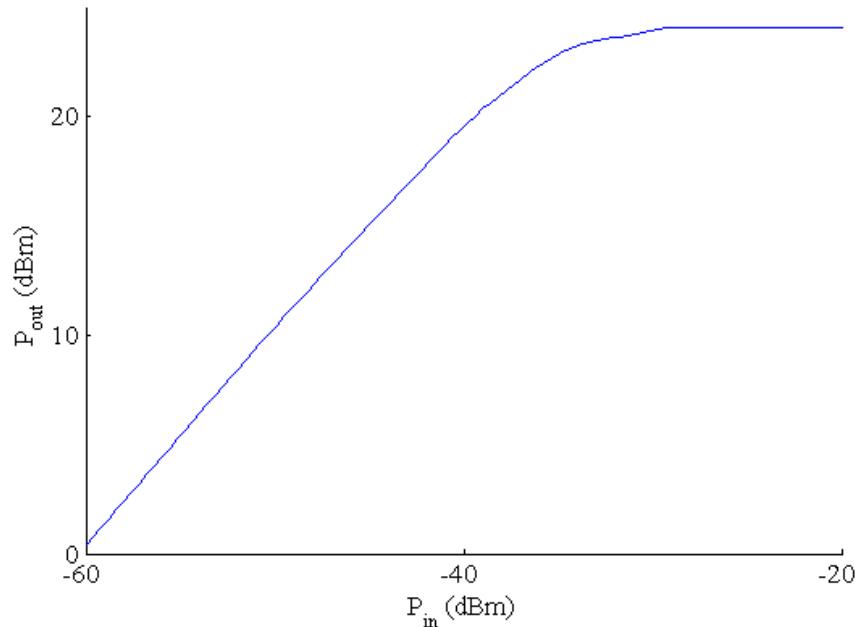


Figure 2. The RF power at the output of the amplifier as a function of the RF power at the input of the amplifier.

Documentation to the file rndnoise.m

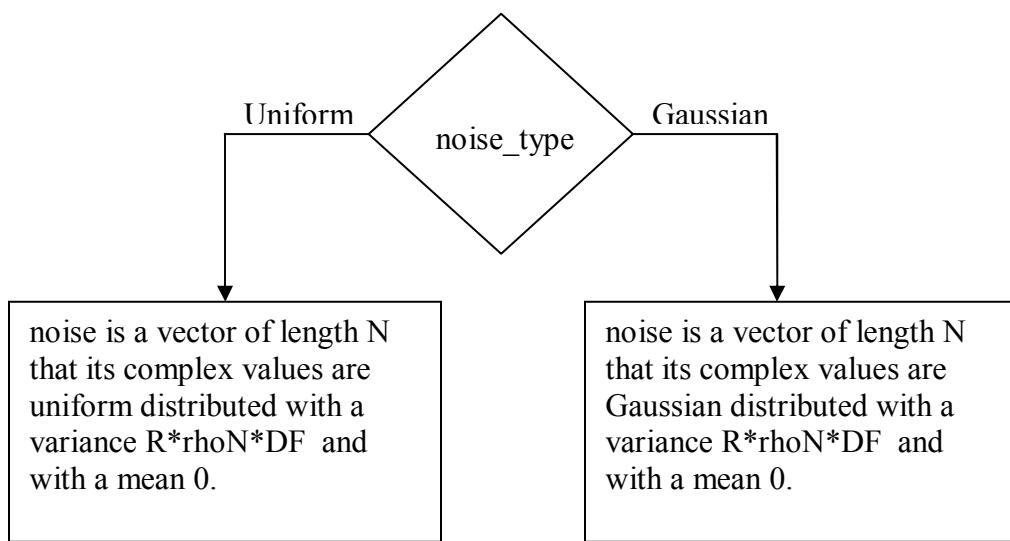
Inputs and outputs variables to rndnoise.m

Num	Input	Output
1	N	noise
2	R	
3	rhoN	
4	DF	
5	noise_type	

List of variables to rndnoise.m

num	name	size	value	meaning
1	N	1x1	10	Number of points in each round-trip time
2	R	1x1	50	The input resistance of the amplifier (Ohm)
3	rhoN	1x1		The noise spectral density (Watt/Hz)
4	DF	1x1		Frequency step-size (Hz)
5	noise_type	1x1		determine the type of the distribution (Gaussian or uniform)
6	noise	1x10		The output noise vector
7	NL	1x1	$\text{sqrt}(2*R*rhoN*DF)$	NL/sqrt(2) is the standard deviation of the noise

Flow chart of rndnoise.m



Documentation to the file flicker_noise_FD.m

The generation of the flicker noise is based on the reference:

N. J. Kasdin, "Discrete Simulation of Colored Noise and Stochastic Processes and $1/f^\alpha$ Power Law Noise Generation," IEEE Proc. 83, 802-827 (1995)

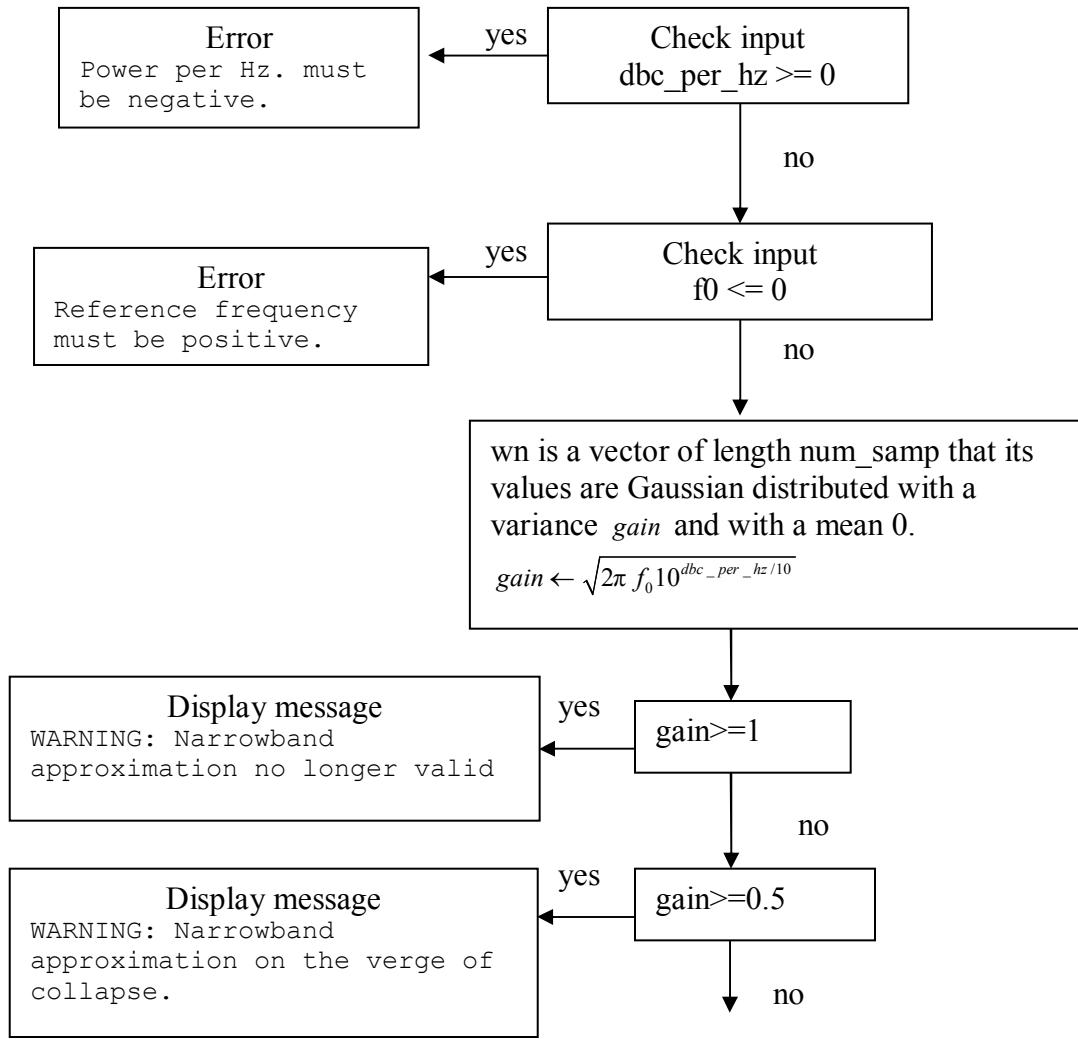
Inputs and outputs variables to flicker_noise_FD.m

Num	Input	Output
1	num_samp	pn
2	f0	theta
3	dbc_per_hz	

List of variables to flicker_noise_FD.m

num	name	size	value	meaning
1	num_samp	1x1	100000	
2	f0	1x1	1e10	
3	dbc_per_hz	1x1		
4	pn	1x100000		
5	theta	1x100000		
6	num_taps	1x1	100	
7	gain	1x1		
8	wn	1x100000		
9	A	1x100000		
10	H	1x100000		
11	WN	1x100000		
12	THETA	1x100000		

Flow chart of the file flicker_noise_FD.m



Documentation to the file filter_8MHz.m

Inputs and outputs to filter_8MHz.m

num	Input	Output
1	freq	fil

List of variables to filter_8MHz.m

num	name	size	value	meaning
1	Gwidth	1x1	8e6	The bandwidth parameter of the filter (Hz)
2	freq_M	1x41	1e6*([-20:1:20]-1)	Measured frequency vector (Hz)
3	FdB_M	1x41		Measured the response of the filter (dB)
4	FdB	1xlength(freq)	interp1(freq_M,FdB_M,freq, 'cubic')	Filter response that is adjusted to the variable freq
5	F	1xlength(freq)	10.^{FdB/10}	Convert from dB to unitless
6	Delay	1x1	2/Gwidth/2/pi*3	Delay of the filter
7	theta	1xlength(freq)	atan(-2*pi*freq*Delay)	The phase of the filter
8	fil	1xlength(freq)	sqrt(F).*exp(i*theta)	The full filter response
9	freq	1xlength(freq)		input frequency vector

Filter response

