DSP Core Functions and Logic Flow

```
import numpy as np
from numpy import fft as fft
import matplotlib.pyplot as plt
import scipy.signal as signal
```

Remove Baseline and Check for Anomalies:

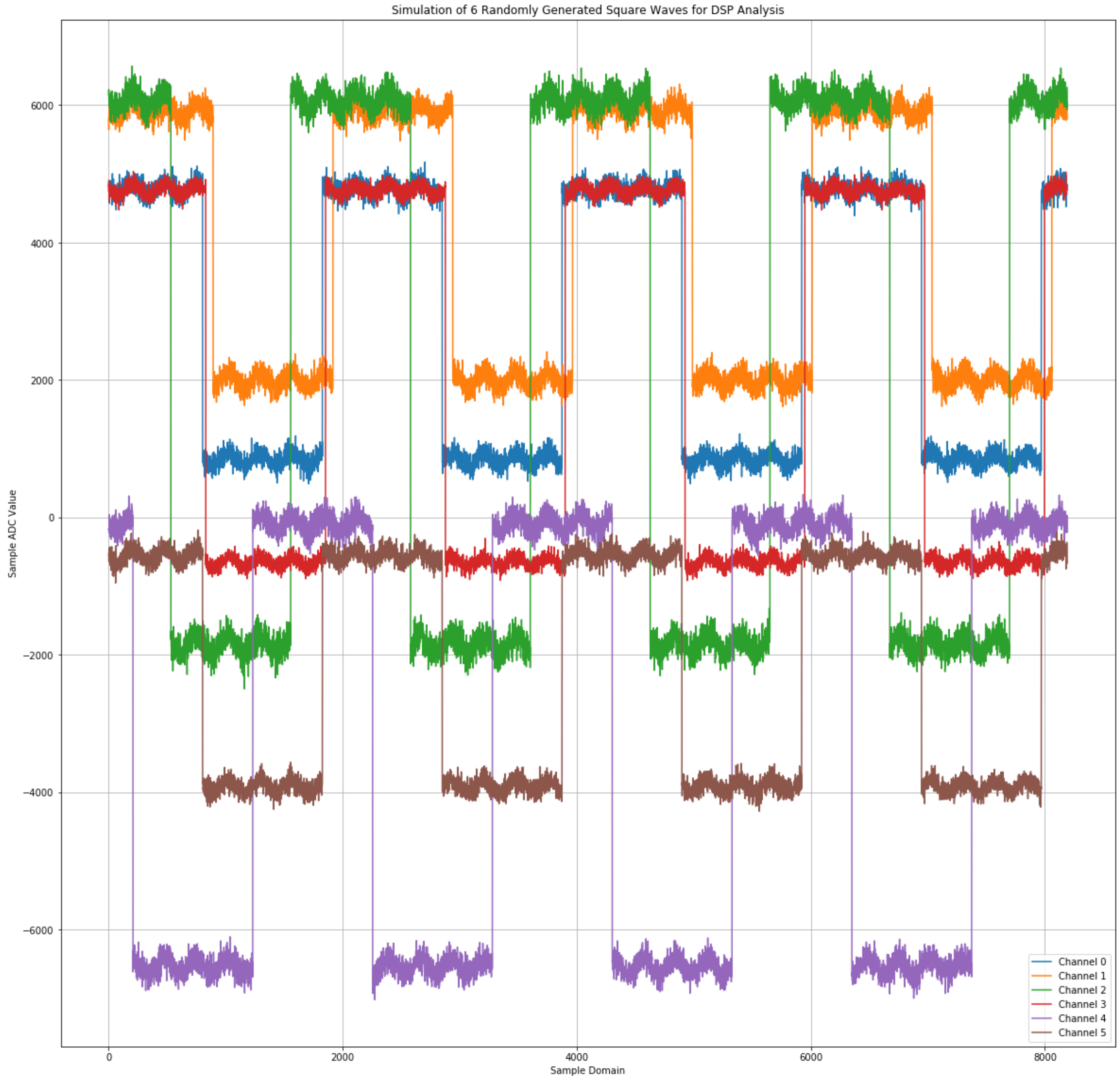
Goal is to quickly find anomalies and filter out any baseline signals in the phase angle and Marine Resistivity data components from the signals. The most reduced, compressed output format possible is best.

```
# Make simulated "baseline" signals and process them with dsp()
def simulate_squares(number_of_channels, dc_offset_max, dc_offs
et_min,
                              amplitude_max, amplitude_min):
    N = 8192  # number of samples
    T = 1 # Sampling period (seconds)
    f_s = 8192  # [Samples/second]
    t = np.linspace(0, N-1, N, endpoint=False)
    offsets = np.random.randint(low=1, high=60, size=number_of_
channels)
    # define the matrix of signals.

    all_channel_wavepacket = np.empty((N, number_of_channels))

    for j in range(number_of_channels):
        TIME_OFFSET = N / offsets[j]  # time offset provided fo
r simulation
        AMP = np.random.randint(amplitude_min, amplitude_max)
# amplitude (in ADC values)
        NOISE_LVL = AMP / np.random.randint(low=10, high=40)  #
Naive way to set noise on the signal (not true SNR)
        DC_OFFSET = np.random.randint(dc_offset_min, dc_offset_
max)  # DC offset in ADC values
        F_tx = 4.00  # Fundamental frequency of the waveform (H
z)
        noise = NOISE_LVL * np.random.normal(0, 1, t.shape)
        pure_sig = AMP * signal.square(2 * np.pi * F_tx * t - T
IME_OFFSET) + NOISE_LVL * np.sin(np.pi* 60 *t) + DC_OFFSET
        sig = pure_sig + noise
        all_channel_wavepacket[:, j] = sig
    return t, all_channel_wavepacket
```

```python
# Plotting the waveforms as a sanity check:
def plot_all_waveforms(t, signals):
    domain_size = t.shape[0]
    plt.figure(figsize=(20,20))
    number_of_channels = signals.shape[-1]
    for p in range(number_of_channels):
        plt.plot(t, signals[:, p], label='Channel %s' % p)
    plt.title(f"Simulation of {number_of_channels} Randomly Gen
erated Square Waves for DSP Analysis")
    plt.xlabel('Sample Domain')
    plt.ylabel('Sample ADC Value')
    plt.grid(True)
    plt.legend()
    plt.show()
```

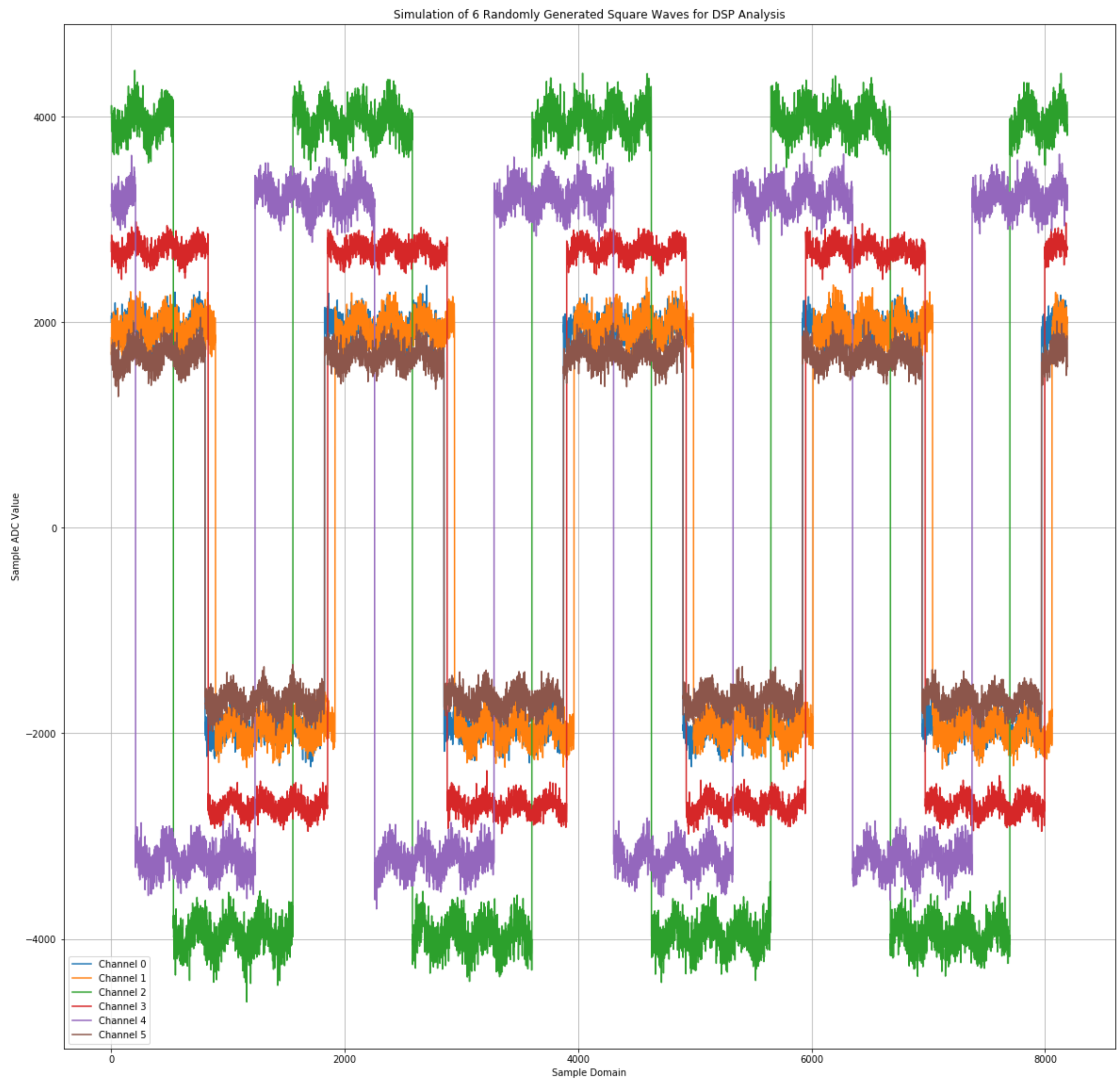
```python
# Simulate 6 channels of baseline noisy data with variable offs
ets within certain ranges.
q_channels = 6  # number of channels
T = 1 # Sampling period (seconds)
f_s = 8192  # [Samples/second]
# Random parameter ranges
base_offset_max = 4000
base_offset_min = -4000
base_amp_max = 4000
base_amp_min = 500

t_domain, baseline_packets = simulate_squares(q_channels, base_
offset_max, base_offset_min,
                                base_amp_max, base_amp_min)
```

```
# Sanity Check plot
plot_all_waveforms(t_domain, baseline_packets)
```




```
def remove_dc_offset(sig):
#     print(f"sig.shape = {sig.shape}")
    q_channels = sig.shape[-1]
    for q in range(0, q_channels):
        offset_average = np.average(sig[:, q])
#         print(f"Waveform Average Value for Channel [q] = {offset_average}")
        sig[:, q] = sig[:, q] - offset_average
    return sig
```

```
# Sanity  check that offset removal still works...
ac_baseline_packets = remove_dc_offset(baseline_packets)
plot_all_waveforms(t_domain, ac_baseline_packets)
```



Filtering

```
def butterworth_digital_lpf(sig, n_samples, f_sample, f_order,
f_cut, analysis_plot=False):
    """
    .. function:: butterworth_analog_lpf
    .. description::
    :param sig:
    :param order:
    :param f_cut:
    :return w:
    :return h:
    :return filt_sig:
    """
    # Define second-order sections representation of the IIR fi
lter.
    sos = signal.butter(f_order, f_cut, 'lp', fs=f_sample, anal
og=False, output='sos')
    # Apply the filter to our signal.
    filt_sig = signal.sosfilt(sos, sig)

    if analysis_plot:
        # Compute the numerator and denominator polynomials of
the IIR filter.
        b, a = signal.butter(f_order, f_cut, 'lp', fs=f_sample,
analog=False)
        # Compute the frequency response of an analog filter.
        w, h = signal.freqs(b, a)
        # and plot results:
        t = np.linspace(0, n_samples - 1, n_samples)
        plot_wave_freqresp_filter(t, sig, filt_sig, w, h, f_ord
er, f_cut)

    return filt_sig
```

```
def plot_wave_freqresp_filter(t, s, filt_s, w, h, f_order, f_c)
:
    """
    .. function:: plot_wave_freqresp_filter
    .. description::
    :param t:
    :param s:
    :param filt_s:
    :param w:
```

```
    :param h:
    :param order:
    :param f_c:
    :return NONE:
    """
    plt.figure(figsize=(17, 5))

    # Raw Waveform
    plt.subplot(131)
    plt.plot(t, s)
    plt.title('Raw Waveform')
    plt.xlabel('Sample Domain')
    plt.ylabel('Sample ADC Value')
    plt.grid(True)

    # Filtered Waveform
    plt.subplot(132)
    plt.plot(t, filt_s)
    plt.title('Filtered Waveform Copy')
    plt.xlabel('Sample Domain')
    plt.ylabel('Sample ADC Value')
    plt.grid(True)

    # Butterworth Filter BODE plot (Right Subplot)
    plt.subplot(133)
    plt.semilogx(w, 20*np.log10(abs(h)))
    plt.title(f'{f_order}-Order \n Butterworth Filter \n
Frequency Response')
    plt.xlabel('Frequency [rad/s]')
    plt.ylabel('Amplitude [dB]')
    plt.margins(0, 0.1)
    plt.grid(which='both', axis='both')
    plt.axvline(f_c, color='green') # cutoff frequency

    plt.tight_layout()
    plt.show()
```

Triggering

```python
def rising_edge_trigger(filt_zeroed_sig, filt_sig_gradient, gra
dient_max, N):
    """
    """
    positive_trigger_indices = (j for j in range(N - 1) if
                               ((filt_sig_gradient[j] >= (2/3) * gr
adient_max) and
                                filt_zeroed_sig[j - 1] < filt_zeroe
d_sig[j]))
    t0 = next(positive_trigger_indices)
#     print(f"First rising trigger found at index {t0}!")
    return t0
```

```python
def falling_edge_trigger(filt_zeroed_sig, filt_sig_gradient, gr
adient_max, N):
    """
    """
    negative_trigger_indices = (j for j in range(N-1, 0, -1)  i
f
                                ((filt_sig_gradient[j] <= (2/3) * -
gradient_max) and
                                 filt_zeroed_sig[j + 1] < filt_zero
ed_sig[j]))
    tf = next(negative_trigger_indices)
#     print(f"Last falling trigger found at index {tf}!")
    return tf
```

```
def set_triggers(s_t_matrix, f_s, filter_order, filter_cut, ana
lysis_plot):
    """
    .. function: set_triggers:
    .. description::
    :param s_t_matrix:
    :param filter_order:
    :param filter_cut:
    :return t0s:
    :return nlengs:
    """
    # definitions:
    q_channels = s_t_matrix.shape[-1]
    n_raw = s_t_matrix.shape[0]
    t0s = []
    nlengs = []

    # for each channel-q:
    for q in range(0, q_channels):
        # filter
        filt_signal = butterworth_digital_lpf(s_t_matrix[:, q],
n_raw, f_s, filter_order, filter_cut, analysis_plot)
        # compute gradient and max gradient value of filtered s
ignal
        filt_g_signal = np.gradient(filt_signal)
        g_max = np.nanmax(filt_g_signal)
        n_filt = filt_signal.shape[0]
        # get first positive trigger t0q
        t0q = rising_edge_trigger(filt_signal, filt_g_signal, g
_max, n_filt)
        # get last negative trigger tfq
        tfq = falling_edge_trigger(filt_signal, filt_g_signal,
g_max, n_filt)
        t0s.append(t0q)
        nlengs.append(np.abs(tfq - t0q))
    return t0s, nlengs
```

```
def shift_signal_to_triggers(time_series_q, t0q, n_min):
    """
    .. function:: shift_signals_to_triggers
    .. description::
    :param time_series_q:
    :param t0q:
    :param n_min:
    :return channel_out:  Output array of length `n_min` for ch
annel-q shifted to the global t0 and trimmed to match `n_min`.
    """
    return np.roll(time_series_q, -t0q)[0: n_min]
```

```
def time_series_conditioning(raw_time_series_matrix, f_s, f_ord
er, f_cut, analysis_plot):
    """
    .. fucntion:: signal_conditioning
    .. description::
    :param time_series_matrix:
    :return win_sig_0: Trigger-windowed ORIGINAL noisy signals
(no filters) array with offset removed and start times (t0q) fo
r channel-q shifted to match using triggers.
    """
    # definitions
    # number of channels q
    q_channels = raw_time_series_matrix.shape[-1]

    # Remove DC offsets
    zeroed_time_series_matrix = remove_dc_offset(raw_time_serie
s_matrix)

    # Locate trigger times and return arrays of t_starts and n_
lengths. Include filter parameters.
    t_starts, n_lengths = set_triggers(zeroed_time_series_matri
x, f_s, f_order, f_cut, analysis_plot)

    # set the minimum trimmed length to match all channels-q
    n_min = np.nanmin(n_lengths)
    # adjust the minimum length to n_min - 1 if the value for n
_min is odd (for simplifying FFTs later)
    if n_min % 2 != 0:
        n_min = n_min - 1
```

```
    # define complex output signal array based on `n_min` and `
q_channels`
    output_signal_matrix = np.empty((n_min, q_channels), dtype=
np.complex64)

    # Iteratively Shift signals in each channel over and trunca
te to match the others
    # based on the start triggers and array lengths determined
by `set_triggers()`
    for q in range(0, q_channels):
#         print(f"Shifting signal start and trimming length for
signal channel {q + 1}")
        output_signal_matrix[:, q] = shift_signal_to_triggers(r
aw_time_series_matrix[:, q], t_starts[q], n_min)

    # testprint
#     print(f"output_signal_matrix dimensions are now {output_s
ignal_matrix.shape}...")
    return output_signal_matrix
```

```
def phase_difference_spectrum(s0k, sqk):
    """
    .. function:: phase_difference_spectrum()
    .. description:: Estimate the phase angle of each waveform
and the associated shift between them, holding
    S_a(k) as a reference wavform and taking the difference of
the derived phase arrays.

    The phase shift corresponds to modulation of the complex pa
rt of the transmitted/
    received waveform, which is an indication of either inducti
ve or capacitive frequency-
    dependent responses of the signal due to the electrical net
work betweewn the electrodes
    formed by the water and target.

    Calculate the phase shift from a reference spectrum (sa_k)
and a shifted spectrum (sb_k)

    :param s0k:
    :param sqk:
    :return phase_shift_spectrum:
    """
    phase0k = np.angle(s0k)
    phaseqk = np.angle(sqk)
    phase_shift = np.subtract(phaseqk, phase0k)

    # Correct phase shift angles for values outside np.pi -- re
moves false positive/negative values.
    for m in range(phase_shift.shape[0]):
        if phase_shift[m] > np.pi:
            phase_shift[m] = 2.00 * np.pi - phase_shift[m]
        elif phase_shift[m] < -np.pi:
            phase_shift[m] = phase_shift[m] + 2.00 * np.pi
        else:
            continue

    return phase_shift
```

```
def apparent_impedance_spectrum(s0k, sqk):
    """
    Estimate the apparent impedance spectrum ||Z(k)||^2 for a s
hunt(s0_k) <--> RX Channel (sq_k) pair by taking the magnitude
    of the difference between the two complex spectra. This yie
lds the REAL part of the complex impedance of the target and wa
ter network
    between RX electrodes and removes the internal real impedan
ce from the transmitter shunt.

    :param s0k:
    :param sqk:
    :return zqk:
    """
    zqk = np.absolute(s0k - sqk)
    return zqk
```

```
# define a DSP signal processing function that calls the other
relevant functions.
def packet_dsp(t, s_t, period, f_s, filter_order=4, filter_cut=
200, filter_analysis_plot=False):
    """
    .. function::
    .. description::
    :param t:
    :param s_t:
    :param tau:
    :param filter_order:
    :param filter_cut:
    :return k_domain:
    :return conditioned_time_series:
    :return marine_ip_k:
    :return marine_r_k:
    """
    # def time_series_conditioning(raw_time_series_matrix, f_s,
f_order, f_cut, analysis_plot
    conditioned_time_series = time_series_conditioning(s_t, f_s
, filter_order, filter_cut, filter_analysis_plot)
    number_of_channels = conditioned_time_series.shape[-1]
#     print("Now computing FFT, Marine Resistivity, and Marine
IP Responses for the packet...")
    N_samples = conditioned_time_series.shape[0]
```

```
    # definitions for numpy arrays and constants
    tau = np.float(period / f_s)
    k_domain = fft.fftfreq(N_samples, tau)
    s_k = np.zeros((k_domain.shape[0], number_of_channels), dty
pe=np.complex64)
    marine_ip_k = np.zeros((k_domain.shape[0], number_of_channe
ls), dtype=np.complex64)
    marine_r_k = np.zeros((k_domain.shape[0], number_of_channel
s), dtype=np.complex64)
    # iterate over all channels to compute the FFT, phase diffe
rence between shunt and channels, and apparent impedance spectr
a between channels
    for q in range(0, number_of_channels):
        # calculate frequency spectra
        s_k[:, q] = fft.fft(conditioned_time_series[:, q])
        marine_ip_k[:, q]= phase_difference_spectrum(s_k[:,0],
s_k[:,q])
        marine_r_k[:, q] = apparent_impedance_spectrum(s_k[:, 0
], s_k[:, q])
    # verbose print
#     print(f"Yielded two matrices: marine_ip_k ({marine_ip_k.s
hape}) and marine_r_k ({marine_r_k.shape}))")
    return k_domain, conditioned_time_series, marine_ip_k, mari
ne_r_k
```

```
def plot_phase_shift_and_magnitude(raw_signal, triggered_signal
, k, marine_ip_k, marine_r_k):

    number_of_channels = raw_signal.shape[-1]
    t_raw = np.linspace(0, raw_signal.shape[0] - 1, raw_signal.
shape[0], endpoint=False)
    t_triggered = np.linspace(0, triggered_signal.shape[0] - 1,
triggered_signal.shape[0], endpoint=False)

    plt.figure(figsize=(20, 20))

    # Raw waveforms replotted for comparison.
    plt.subplot(221)
    for p in range(number_of_channels):
        plt.plot(t_raw, raw_signal[:, p], label='Channel %s' %
p if p != 0 else 'Transmit Shunt')
    plt.title(f"Simulation of {number_of_channels} Single Packe
```

```
t of \n Randomly Generated Square Waves for DSP Analysis")
    plt.xlabel('Sample Number')
    plt.ylabel('Shifted Sample ADC Value (Arb. Units)')
    plt.grid(True)
    plt.legend()

    # Triggered, AC-only waveforms plotted for comparison.
    plt.subplot(222)
    for p in range(number_of_channels):
        plt.plot(t_triggered, triggered_signal[:, p], label='Ch
annel %s' % p if p != 0 else 'Transmit Shunt')
    plt.title(f"Simulation of {number_of_channels} Single Packe
t of \n Randomly Generated Square Waves Shifted and Trimmed to
Match\n in Signal Conditionining Stage")
    plt.xlabel('Sample Number')
    plt.ylabel('Shifted Sample ADC Value (Arb. Units)')
    plt.grid(True)
    plt.legend()

    # Triggered Phase Shift across all channels
    plt.subplot(223)
    for p in range(1, number_of_channels):
        plt.plot(fft.fftshift(k), fft.fftshift(marine_ip_k[:, p
]), label='Channel %s' % p if p != 0 else 'Transmit Shunt')
    plt.title('Single Simulated Baseline Packet $p$ \n Marine I
P Response $\Delta\phi_{p}(k)$ by Frequency')
    plt.xlabel('Frequency $\omega$ Domain radians/s')
    plt.ylabel('Corrected Phase Angle Deflection ${S_a}\angle{S
_b}$ [Radians]')
    plt.xlim(0,200)
    plt.ylim(-np.pi, np.pi)
    plt.grid(True)
    plt.legend()

    # Triggered ||Z||^2 across all channels
    plt.subplot(224)
    for p in range(1, number_of_channels):
        plt.semilogy(fft.fftshift(k), fft.fftshift(marine_r_k[:
,p]), label='Channel %s' % p if p != 0 else 'Transmit Shunt')
    plt.title('Single Simulated Baseline Packet $p$ \n Marine R
esistivity Response $||Z_{p}(k)||^{2}$ by Frequency')
    plt.xlabel('Frequency $\omega$ Domain radians/s')
```

```
    plt.ylabel('Spectral Intensity')
    plt.grid(which='both', axis='both')
    plt.xlim(0,200)
#     plt.ylim(1000, np.max(fft.fftshift(marine_r_k[:200])))
    plt.legend()

    plt.tight_layout()
    plt.show()
```

```
k, conditioned_signals, marine_ip_k, marine_r_k = packet_dsp(t_
domain, baseline_packets, T, f_s, filter_order=4, filter_cut=20
0)
```

```
plot_phase_shift_and_magnitude(baseline_packets, conditioned_si
gnals, k, marine_ip_k, marine_r_k)
```

```
/anaconda3/lib/python3.6/site-packages/numpy/core/_asarray.py:85: Complex
Warning: Casting complex values to real discards the imaginary part
  return array(a, dtype, copy=False, order=order)
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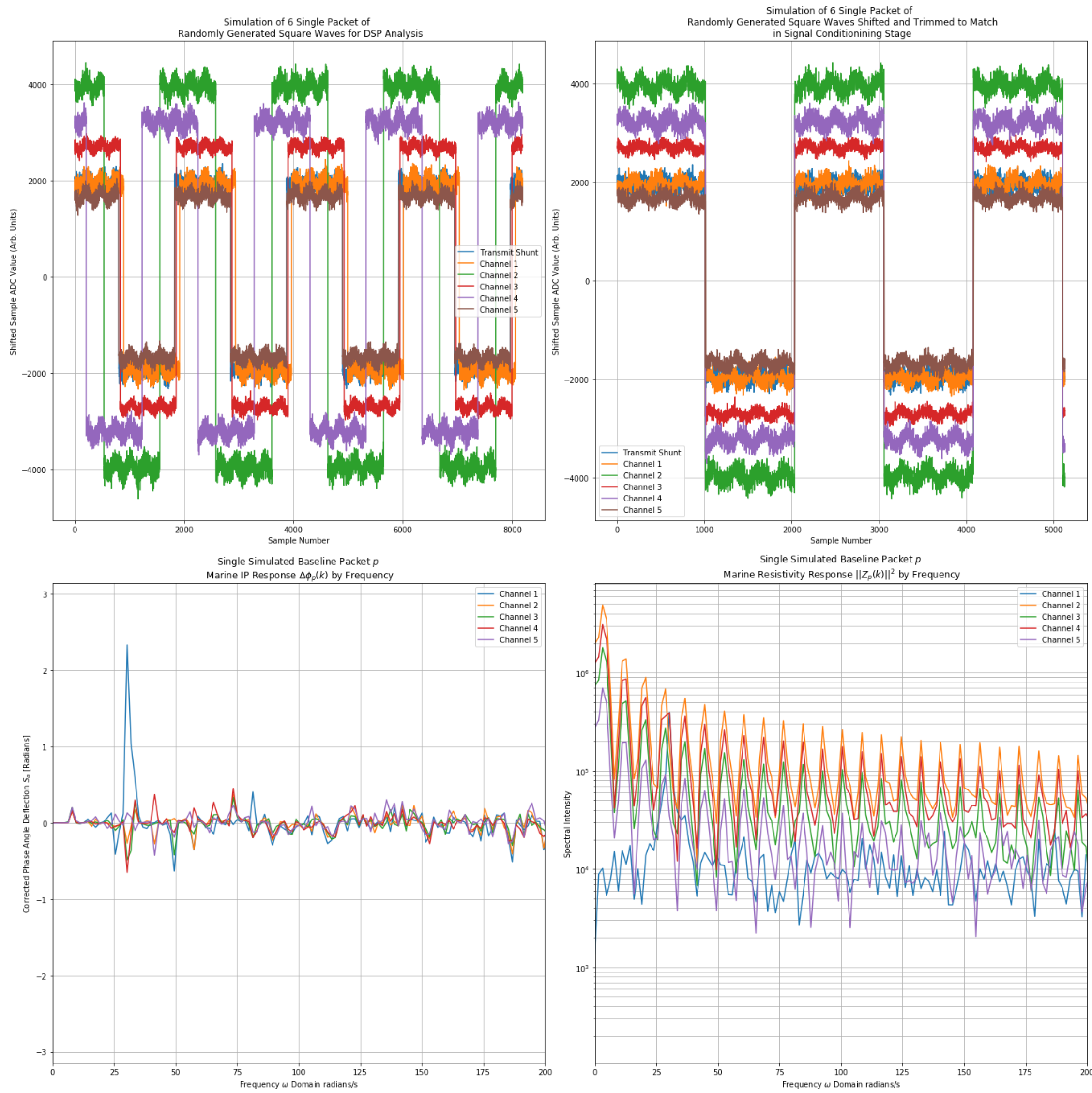
  return array(a, dtype, copy=False, order=order)
```



Baseline Generation Continued: Simulating a Multi-Packet Baseline

with square waves of slightly variable amplitude, random time-offset and more-or-less fixed noise level.

```
n_samples_base = 8192 # per packet
# p_packets = 150  # number of packets to generate and average
p_packets_base = 500  # number of packets to generate and avera
ge


# # Simulate 6 channels of baseline noisy data with variable of
fsets within certain ranges.
q_channels = 6  # number of channels in each packet with simula
ted waveforms.
T = 1 # Sampling period (seconds)
f_s = 8192  # [Samples/second]
# Random parameter ranges
base_offset_max = 4000
base_offset_min = -4000
base_amp_max = 4000
base_amp_min = 500

baseline_packet_set = np.empty((n_samples_base, q_channels, p_p
ackets_base))

for p in range(0, p_packets_base):
    t_domain, baseline_packet_set[:, :, p] = simulate_squares(q
_channels, base_offset_max, base_offset_min, base_amp_max, base
_amp_min)

average_baseline_packet = np.average(baseline_packet_set, axis=
2)
average_baseline_packet.shape
```

```
(8192, 6)
```

To Highlight the Order of Operations:

```
k, conditioned_baseline, baseline_ip_response, baseline_r_respo
nse = packet_dsp(t_domain, average_baseline_packet, T, f_s, fil
ter_order=4, filter_cut=200)
```

```
plot_phase_shift_and_magnitude(average_baseline_packet, conditi
oned_baseline, k, baseline_ip_response, baseline_r_response)
```

```
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```
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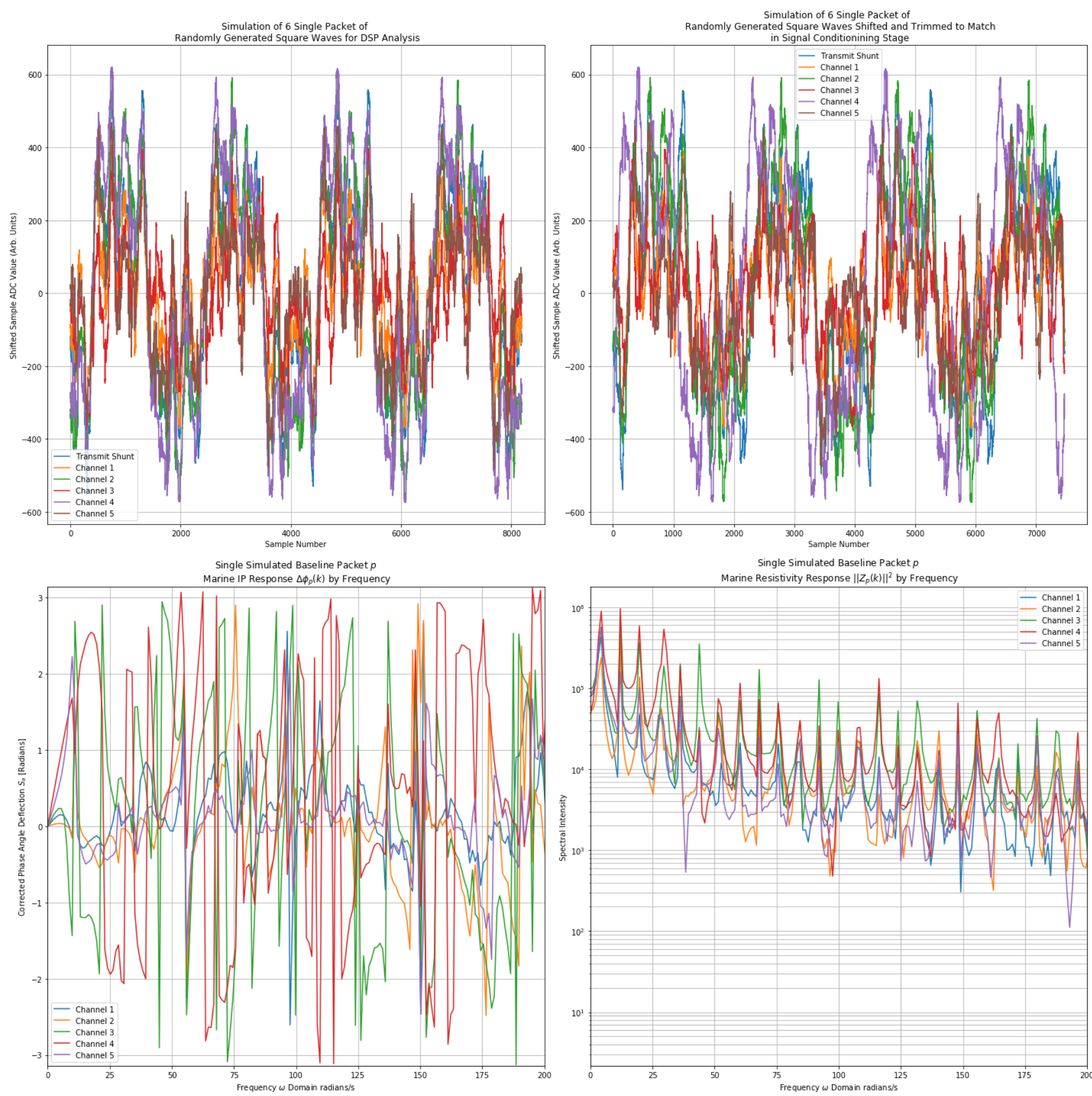
```



Notice how this data set is substantially messier, even **with triggering logic** because the spectrum is applied after the time series are averaged. Strangely, the Marine resistivity data looks a bit tighter in this simulation. Keep in mind, the conditions are more or less random between the packets -- however this highlights the need for properly ordered DSP core functions, as the following will show.

```
# more-or-less-global constants
tau = np.float(T / f_s)
#
k_domain = fft.rfftfreq(n_samples, tau)
# options
maxfreq = 200 # maximum frequency for truncating spectra (Hz)

# array definitions for simulated data
baseline_packet_set = np.empty((n_samples, q_channels, p_packet
s_base))

#
mip_set= np.empty((maxfreq, q_channels, p_packets_base))
mr_set = np.empty((maxfreq, q_channels, p_packets_base))

# stack all the packets into the p_packets_base axis of the set
s.
for p in range(0, p_packets_base):
    # one would replace the following line with a call to the r
aw data for packet-p in the baseline set.
    t_domain, baseline_packet_set[:, :, p] = simulate_squares(q
_channels, base_offset_max, base_offset_min, base_amp_max, base
_amp_min)
    _, _, mip, mr = packet_dsp(t_domain, baseline_packet_set[:,
:, p], T, f_s, filter_order=4, filter_cut=200)
    mip_set[:, :, p] = mip[:maxfreq]
    mr_set[:, :, p] = mr[:maxfreq]

# average along the p_packets_base axis. Generates a (k_frequen
cies X q_channels) array of real values.
avg_ip_response = np.average(mip_set, axis=2)
avg_r_response = np.average(mr_set, axis=2)

print(f"Packet Generation and Averaging Completed for {p_packet
s_base} baseline packets!")
```

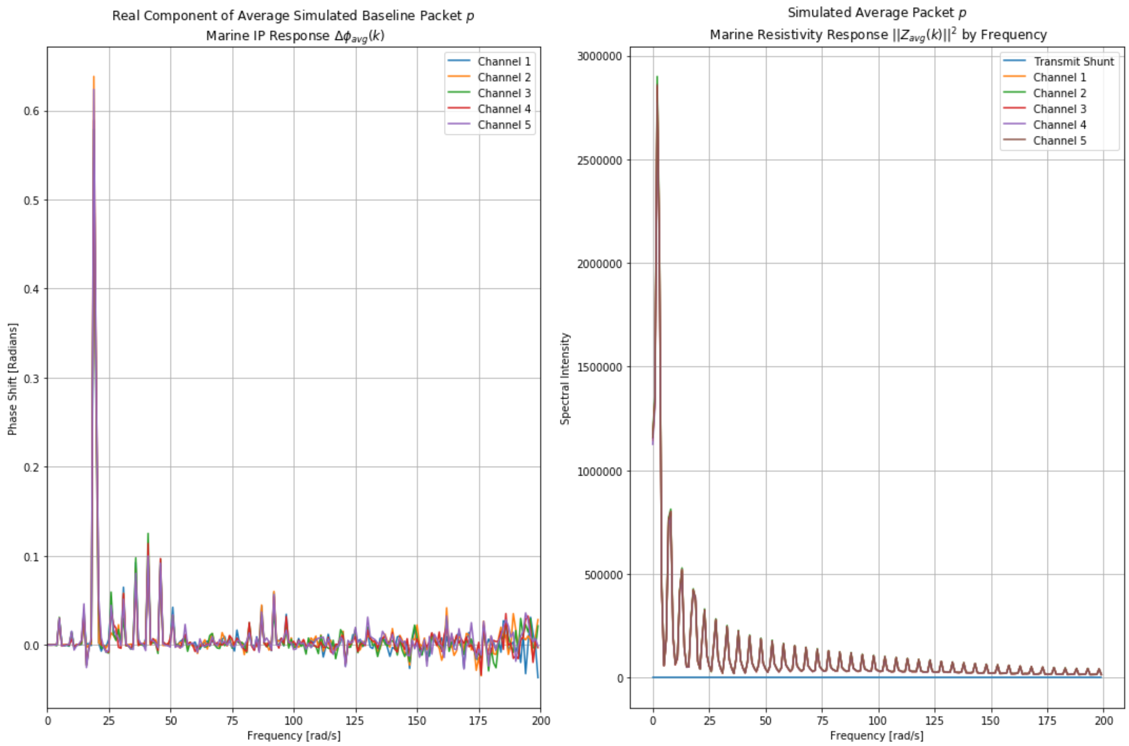
```
/anaconda3/lib/python3.6/site-packages/ipykernel_launcher.py:20: ComplexW
arning: Casting complex values to real discards the imaginary part
/anaconda3/lib/python3.6/site-packages/ipykernel_launcher.py:21: ComplexW
arning: Casting complex values to real discards the imaginary part


Packet Generation and Averaging Completed for 500 baseline packets!
```

```python
def plot_only_phase_shift_and_z_mag(k_domain, ip_freqresp, z_fr
eqresp, maxfreq, avg=False):
    """
    .. function::
    .. description:: Plots the real and imaginary parts of each
spectrum in 4 subplots.
    :param truncated_frequency_domain:
    :param truncated_ip_freqresp:
    :param truncated_z_freqresp:
    :param avg: default False
    :return None:
    """

    number_of_channels = ip_freqresp.shape[-1]
    frequencies = k_domain[:maxfreq]

    if avg:
        avg_or_sing = "Average"
        packet_type = "{avg}"
    else:
        avg_or_sing = "Single"
        packet_type = "{p}"

    plt.figure(figsize=(15, 10))

    # Real Component of Phase Shift
    plt.subplot(121)
    for q in range(1, number_of_channels):
        plt.plot(frequencies, ip_freqresp[:, q], label='Channel
%s' % q)
    plt.title(f"Real Component of {avg_or_sing} Simulated Basel
ine Packet $p$ \n Marine IP Response $\Delta\phi_{packet_type}
(k)$")
    plt.xlabel('Frequency [rad/s]')
```

```
    plt.ylabel('Phase Shift [Radians]')
    plt.xlim(0, maxfreq)
    plt.grid(True)
    plt.legend()

    # Real Compoenent of ||Z||^2 across all channels
    plt.subplot(122)
    for q in range(0, number_of_channels):
        plt.plot(frequencies, z_freqresp[:, q], label='Channel 
%s' % q if q != 0 else 'Transmit Shunt')
    plt.title(f"Simulated {avg_or_sing} Packet $p$ \n Marine Re
sistivity Response $||Z_{packet_type} (k)||^{2}$ by Frequency")
    plt.xlabel('Frequency [rad/s]')
    plt.ylabel('Spectral Intensity')
    plt.grid(which='both', axis='both')
    plt.legend()

    plt.tight_layout()
    plt.show()
```

```
# plot_only_phase_shift_and_z_mag(k_domain, avg_ip_response, avg_r_response, maxfreq)
plot_only_phase_shift_and_z_mag(k_domain, avg_ip_response, avg_r_response, maxfreq, avg=True)
```



Generate a Variable Simulation "Measurement Set"

Creating one more set of packets, maybe 20 or so, with random values again but having a constrained phase offset, we can test baseline subtraction.

```
n_samples_meas = 8192 # per packet
p_packets_meas = 2 # number of packets to generate and average
# Simulate 6 channels of baseline noisy data with variable offs
ets within certain ranges.
q_channels_meas = 6  # number of channels in each packet with s
imulated waveforms.
# T_meas = 1 # Sampling period (seconds)
# f_s = 8192  # [Samples/second]
# Random parameter ranges
base_offset_max_meas = 4000
base_offset_min_meas = -4000
base_amp_max_meas = 4000
base_amp_min_meas = 500
measurement_packet_set = np.empty((n_samples, q_channels, p_pac
kets))

for p in range(0, p_packets):
    t_domain, measurement_packet_set[:, :, p] = simulate_square
s(q_channels, base_offset_max, base_offset_min, base_amp_max, b
ase_amp_min)
```

```
# take one of these packets and subtract the baseline, say pack
et 0
measurement_packet_1 = measurement_packet_set[:, :, 0]
```

```
# perform DSP on this packet having 6 channels.
k, conditioned_packet_1, packet_1_ip_response, packet_1_r_respo
nse = packet_dsp(t_domain, measurement_packet_1, T, f_s, filter
_order=4, filter_cut=200)
```

```
# plot the packet BEFORE average baseline subtraction:
plot_phase_shift_and_magnitude(measurement_packet_1, conditione
d_packet_1, k, packet_1_ip_response, packet_1_r_response)
```

```
/anaconda3/lib/python3.6/site-packages/numpy/core/_asarray.py:85: Complex
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```
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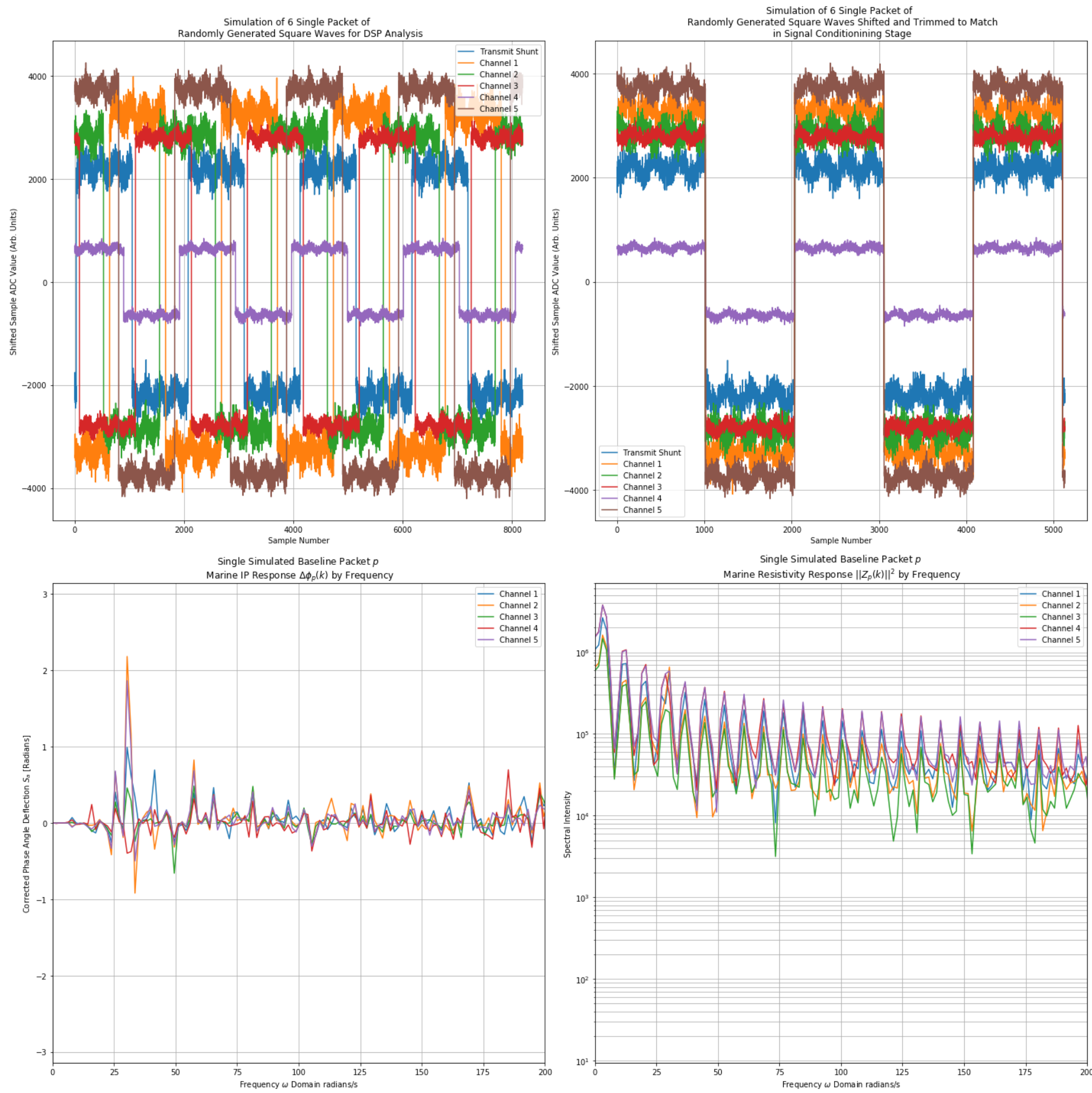


```python
def subtract_baseline(measurement_packet_spectrum, avg_frequency_response, maxfreq):
    """
    .. description:: works the same for both types of spectra. Simple subtraction
    of the baselines, but with some truncating to ensure they're the same dimemsions for
    broadcasting.
    """
    return measurement_packet_spectrum[:maxfreq] - avg_frequency_response
```

```
packet_1_ip_base_subtracted = subtract_baseline(packet_1_ip_res
ponse, avg_ip_response, maxfreq)
```

```
packet_1_r_base_subtracted = np.abs(subtract_baseline(packet_1_
r_response, avg_r_response, maxfreq))
```

```
 plot_only_phase_shift_and_z_mag(k_domain, packet_1_ip_base_sub
tracted, packet_1_r_base_subtracted, maxfreq, avg=False)
```

```
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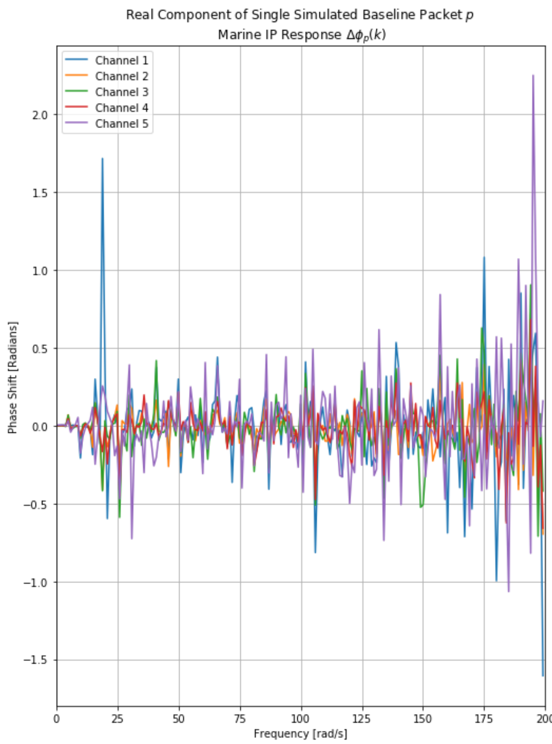

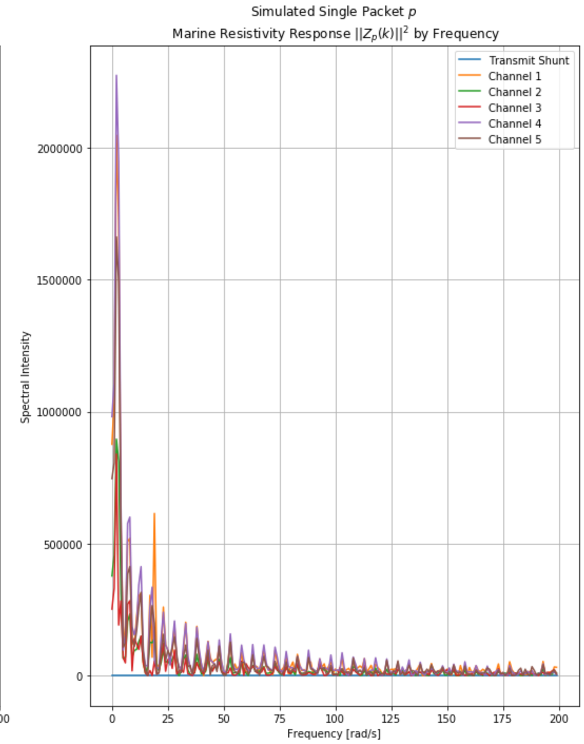

At this point, normalizing the frequency spectra seems like the way to go to clean things up even further. The two spectra above still show less variance than the earlier spectra generated by the data, but it can probably be made better with the introduction of normed amplitudes in the phase difference such that common frequency responses between baseline and measurement are fully cancelled out.

Also, it is again important to note here that the data to this point has been completely simulated using random processes, so we do not expect any particular patterns to emerge yet.

Another possibility is taking the normalized coherence between the two spectra or looking at other ways of comparing the normalized densities between the spectra.

First, it is simplest to just compute the norms of the waveforms and normalize them against one another to scale up or down. Then the baseline removal should be far more effective and highlight only the phase shift frequency repsonses that differ between the two (average and measurement) signals.

Normalizing the spectra before performing a baseline subtraction: