

# GROUP DELAY MATCH IN SPLIT-LEVEL COMBINING

## INTRODUCTION

Three parameters are important when coherently combining CW signals; these are the amplitude, frequency and phase of the summing signals.

However, a fourth parameter needs to be considered when coherently combining wideband (modulated) signals. This additional parameter is the group delay through the two parallel signal paths, that if matched, guarantees that the achieved phase match is valid not only at a single frequency, but throughout the whole modulated bandwidth. As a general rule, the wider the modulated bandwidth, the more accurate the delay match have to be.

In our case, for a FM broadcast signal, the modulated bandwidth can extend past  $\pm 100\text{KHz}$  from the center of the channel. To find the required accuracy, we will study the effect the group delay mismatch has on FM performance, this way setting a maximum limit of delay mismatch the system can tolerate.

## ANALYSIS

To simplify our analysis we will assume that neither transmitter adds any distortion to their respective signal. This means that the system linear distortion will only be a function of the delay and phase relationship between the main and digital transmitter paths.

The drawing below shows the two different signal paths summed with an output combiner as implemented in Split-Level combining. It can be seen that by allowing a delay mismatch, a tapped-delay line filter network is formed, as a sample of the FM input signal is delayed and fed forward to be summed with the main FM path.

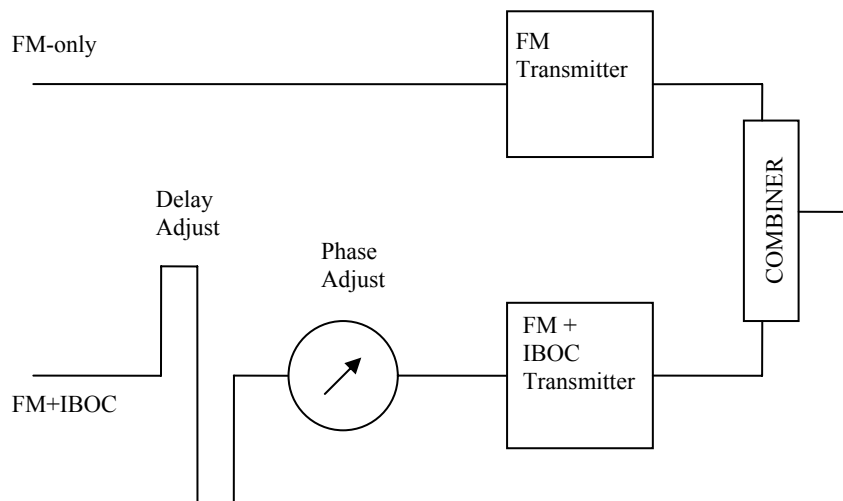


Fig 1. Split-Level combining, when mismatched, forms a delayed-line filter network.

## DELAY MISMATCH

A spreadsheet was created to compute the frequency response of this network, as a function of delay mismatch and output coupling. It was then determined that the worst frequency response for the Split-Level combining is obtained for its tightest coupling coefficient of 3dB. ***This will be the coupling coefficient (3dB) used for the rest of this study.*** In the two graphs below, the network insertion loss and the deviation from constant group delay is presented as a function of delay mismatch.

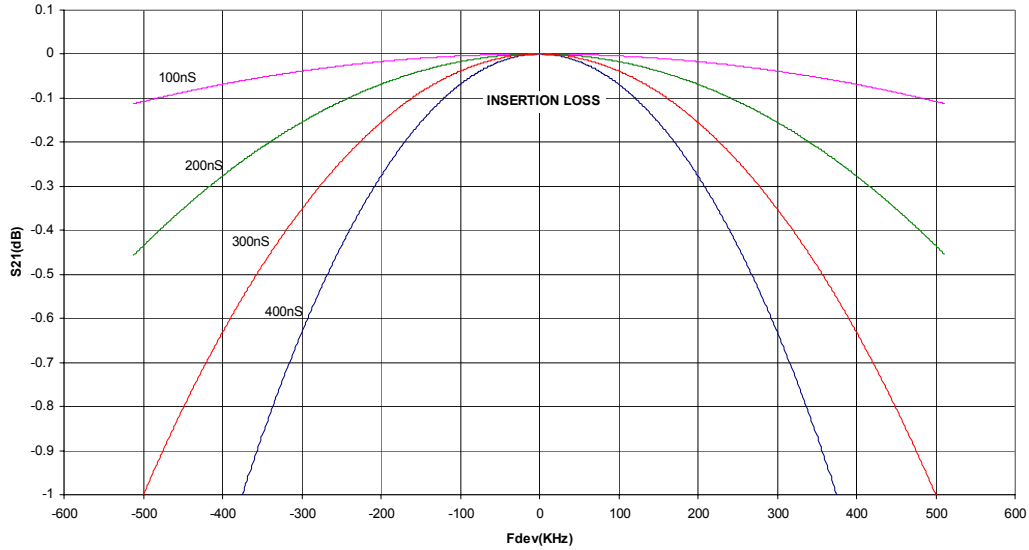


Fig 2. Insertion loss for different delay mismatch. No phase mismatch considered.

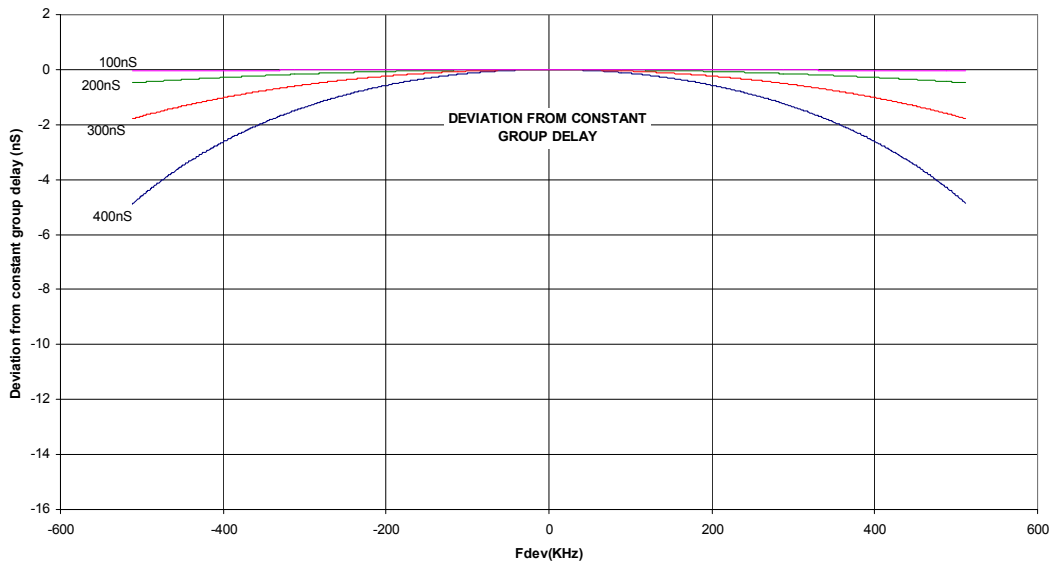


Fig 3. Deviation from constant group delay for different delay mismatch. No phase mismatch considered.

The phase being perfectly matched at the center of the band guarantees the minimum insertion loss at the center frequency. As the frequency deviates off the center, the increasing phase mismatch increases the insertion loss of the combining system.

As the group delay remains relatively constant, we can expect the degradation in system FM performance to be related only to the linear amplitude distortion.

A linear simulation of a FM-modulated signal passing through this network was performed, and the demodulated FM parameters were tabulated below.

| Delay<br>(ns) | Phase<br>(Deg) | No de-<br>emphasis<br>Sync AM<br>(dB) | Stereo<br>Separation<br>(dB) | With de-<br>emphasis<br>L-Ch<br>Total Dist<br>(%) |
|---------------|----------------|---------------------------------------|------------------------------|---|
| 50            | 0              | -84.2                                 | 100                          | 0.003   |
| 100           | 0              | -77.2                                 | 88.9                         | 0.004   |
| 200           | 0              | -65.8                                 | 76.8                         | 0.003   |
| 300           | 0              | -58.8                                 | 69.9                         | 0.006   |
| 400           | 0              | -53.8                                 | 64.9                         | 0.003   |

Table 1. Demodulated FM performance for different delay mismatch. No phase mismatch considered.

From the table above we see how most of the parameters worsen as the delay mismatch is increased. Total distortion, however, remains low for all delay mismatch considered.

However, satisfactory results can be expected with delay mismatch as high as 200ns, as long as a good phase match is maintained.

## DELAY AND PHASE MISMATCH

Next, we will see the effect that phase mismatch has on system performance. From a frequency response viewpoint, a phase mismatch in addition to a delay mismatch, causes the resonant frequency to shift away from the center, creating a non-symmetrical slope across the channel.

As an example, a phase mismatch of 15 degree was introduced, and the frequency response was plotted in the graphs below.

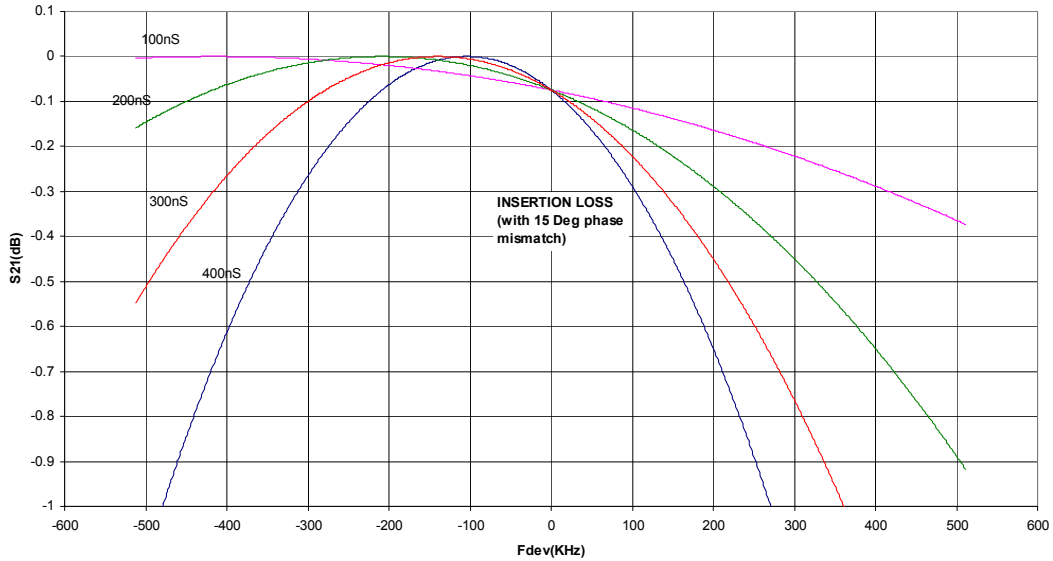


Fig 4. Insertion loss for different delay mismatch.  
Phase mismatch of 15 Deg.

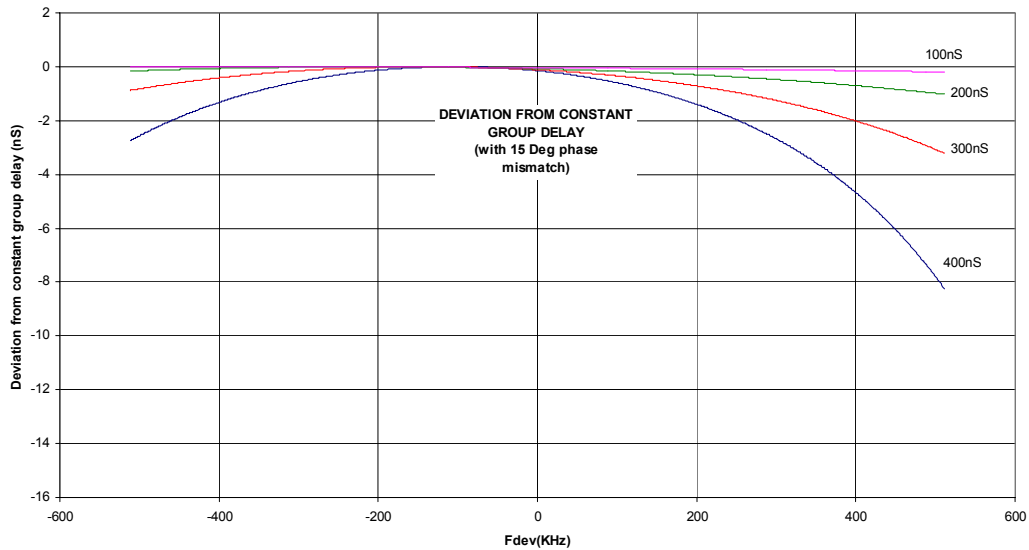


Fig 5. Deviation from constant group delay for different delay mismatch.  
Phase mismatch of 15 Deg.

With the resonant frequency shifted from the center, the peak-to-peak insertion loss distortion increases. Also, the response is not symmetrical, which can further influence in the quality of the FM demodulated signal.

In the same manner, a linear simulation was done of an FM modulated signal passing through this network, for different delay and phase mismatch applied, and the results were summarized in the tables below.

| Delay (ns) | Phase (Deg) | No de-emphasis Sync AM (dB) | Stereo Separation (dB) | With de-emphasis L-Ch Total Dist (%) |
|------------|-------------|-----------------------------|------------------------|--------------------------------------|
| 50         | 5           | -67.7                       | 100                    | 0.004                                |
| 100        | 5           | -61.7                       | 89.4                   | 0.004                                |
| 200        | 5           | -55.5                       | 76.9                   | 0.005                                |
| 300        | 5           | -51.6                       | 69.9                   | 0.005                                |
| 400        | 5           | -47.7                       | 64.9                   | 0.003                                |

Table 2. Demodulated FM performance for different delay mismatch. A phase mismatch of 5° was applied.

| Delay (ns) | Phase (Deg) | No de-emphasis Sync AM (dB) | Stereo Separation (dB) | With de-emphasis L-Ch Total Dist (%) |
|------------|-------------|-----------------------------|------------------------|--------------------------------------|
| 50         | 10          | -61.7                       | 100                    | 0.004                                |
| 100        | 10          | -55.7                       | 89.5                   | 0.004                                |
| 200        | 10          | -49.7                       | 76.7                   | 0.004                                |
| 300        | 10          | -46.04                      | 69.9                   | 0.004                                |
| 400        | 10          | -43.4                       | 64.8                   | 0.004                                |

Table 3. Demodulated FM performance for different delay mismatch. A phase mismatch of 10° was applied.

| Delay (ns) | Phase (Deg) | No de-emphasis Sync AM (dB) | Stereo Separation (dB) | With de-emphasis L-Ch Total Dist (%) |
|------------|-------------|-----------------------------|------------------------|--------------------------------------|
| 50         | 15          | -58.2                       | 100                    | 0.004                                |
| 100        | 15          | -52.2                       | 89                     | 0.004                                |
| 200        | 15          | -46.1                       | 77                     | 0.004                                |
| 300        | 15          | -42.6                       | 69.9                   | 0.004                                |
| 400        | 15          | -40                         | 64.8                   | 0.004                                |

Table 4. Demodulated FM performance for different delay mismatch. A phase mismatch of 15° was applied.

## CONCLUSION

For the range of delay and phase studied, results have shown that:

- Delay mismatch creates linear amplitude distortion, but no significant linear phase distortion. The resultant frequency response is that of a bandpass filter.
- Phase mismatch, in addition to a delay mismatch, shifts the resonant frequency away from the center of the channel.
- Stereo Separation is mostly dependent on delay mismatch, but not on phase mismatch.
- Synchronous AM is dependent on both delay and phase mismatch.
- Total distortion is independent on either delay or phase mismatch
- Delay mismatches of 50ns or less are hardly noticeable in the FM system performance.
- Delay mismatches up to 100ns can be allowed, as long as the phase mismatch is held within 10 degrees.