Simultaneous Tracking of Multiple Signals Using a Thinned Array Antenna System

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ABSTRACT

Multiple same-frequency signals including direct/multipath signals are distinguished and individually tracked by measuring phase differences between sum and error channels of thinned array systems.

KEY WORDS

Thinned array; Multiple Users; Phase discrimination; error channels.

INTRODUCTION

Using IF phase differences, multiple Users can be tracked at the same frequency, within the same beamwidth, simultaneously.

SIMULTANEOUS TRACKING OF MULTIPLE SIGNALS USING A THINNED ARRAY ANTENNA SYSTEM

Multiple signals incident on wireless communication systems are distinguished from one another by utilizing frequency differences, CDMA, TDMA or resolution by the antenna system's beamwidth. However, signals at the same frequency that fall within the antenna system's viewing angle, such as multipath/direct signals, are not readily distinguished. Conventional antenna systems limit angular resolution to one beamwidth of the antenna system, thereby excluding resolution of direct and multipath signals that fall within the antenna system's view.

This paper explores a scheme, whereby direct and multipath signals or multiple signals at the same frequency falling within view of the antenna system can be readily distinguished and a means provided to track any or all of the incident signals. The antenna system's angular resolution capability is thereby effectively enhanced.

It has been shown (Refs. 1-5) that sets of both real and imaginary spatial frequencies (SFs) can be derived from the measured phase differences between elements of a thinned array of antenna elements. Efforts have primarily been directed to developing the SFs at baseband. This paper makes the case for establishing a set of SFs at IF as well. A thinned array of three elements with spacings of $2\ {}^{\lambda}/_{2}$ and $3\ {}^{\lambda}/_{2}$, for example, can produce eight derived contiguous real and imaginary SFs at baseband and also at IF. (Tables 1 and 2)

A summation of the derived real SFs (cos terms) results in a conventional sum pattern with an on-axis max (sum pattern) while a summation of derived imaginary SFs (sin terms) results in an error pattern with an on-axis null. ($\triangle$ pattern, Fig.1) There is an abrupt change in sign of the error channel amplitude where the error pattern crosses $\theta = 0^\circ$ (Point A in Fig.1). This abrupt change in sign is due to a phase reversal when the cross-over point of the error channel passes through $\theta = 0^\circ$. Sufficient amplitude in formation is thereby available to track a single signal incident on the system.

Two signals at the same frequency, eg., direct and multipath signals, incident on an array present a more complex problem. For example, two signals of equal amplitude and separated by 8° result in a sum pattern, which is the average of the two incident signals and points to a direction between the two source locations (SUM Fig. 2). Similarly, the error pattern for the two sources is an average where the zero cross-over is somewhere between the two sources (Δ pattern). Figure 2 also shows the error patterns for each of the two individual sources that would be present if the other were not present ($\Delta 1$ and $\Delta 2$). An abrupt phase reversal occurs when the average error pattern crosses $\theta = 0^\circ$ as when a single signal is incident (point A in Fig. 2) and in addition is accompanied by a reversal in amplitude sign. Scanning the error pattern will result in additional phase reversals as well: a scan to the right will produce an abrupt phase reversal at point B (Fig. 2) while a scan to the left produces an abrupt change at point C. At point B, the resultant average error pattern is due entirely to that of error pattern $\Delta 1$ because $\Delta 2=0$ at B. At point C, the resultant average error pattern is due only to error pattern $\Delta 2$, since $\Delta 1=0$. No change in error channel amplitude at BB occurs in either of the latter cases. Both sources can be individually acquired and tracked however, by generating two error channels, one for each signal and locking on phase reversals. One error channel is scanned to point B where the phase reversal is used to acquire and track one of the signal sources, while the other error channel is scanned to point C in order to acquire the second signal. The phase reversals at B and C can, therefore, be used to simultaneously acquire and track the individual signal sources.

Carrier phase information for the signal sources at baseband as shown in Fig. 2 is not available since the carrier has been removed. Phase information is available, however, at IF, where carrier representation is available. It is therefore necessary to establish a set of SFs at IF (Table 2). A representative sum pattern of real SFs at IF with phase information present is shown in Fig 3, while a representative error pattern with phase information is shown in Fig 4. Note the phase reversals that occur at all zero amplitude crossings. A measure of phase difference between the sum and error channels at IF produces the phase reversals as described above.

Each additional signal incident on the array will present an additional zero crossing and therefore another phase reversal, requiring an additional error channel to acquire and track the signal.

A sum channel that contains desired intelligence can distinguish two sources by multiplying the sum channel and the error channel that is pointed to the undesired signal, since an error pattern that is pointed to a signal source contains zero output from that source.

REFERENCES

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4. U.S. Patent # 5339 284, "Signal Processor for Elimination of Sidelobe Responses and Generation of Error Signals", assigned to Fredrick Herold & Associates, Inc., 1994.
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Attachments (Tables and Figures)

MathCad Equations used to create graphics:

$$N := 1 .. 8$$

$$\theta := 340 .. 380$$

$$\delta 1 := 0$$

$$\delta 0 := -4 \cdot \frac{\pi}{180} \qquad \delta 2 := 4 \cdot \frac{\pi}{180}$$

$$SIN(\theta) := \sin\left(\frac{\pi}{180} \cdot \theta\right)$$

$$\gamma 1_{\theta} := (\pi \cdot 0.5 \cdot SIN(\theta)) + \delta 0 \qquad \gamma 0_{\theta} := (\pi \cdot 0.5 \cdot SIN(\theta)) + \delta 0$$

$$\gamma 2_{\theta} := (\pi \cdot 0.5 \cdot SIN(\theta)) + \delta 2$$

$$s1_{\theta} := \sum_{N} \sin\left(N \cdot \gamma 1_{\theta}\right) + \gamma 1_{\theta}$$

$$s0_{\theta} := \sum_{N} \sin\left(N \cdot \gamma 0_{\theta}\right) + \gamma 0_{\theta}$$

$$s2_{\theta} := \sum_{N} \sin\left[N \cdot (\gamma 2)_{\theta}\right] + \gamma 2_{\theta}$$

$$s3_{\theta} := \sum_{N} \cos\left(N \cdot \gamma 0_{\theta}\right) \qquad s3_{\theta} := \sum_{N} \sin\left(-N \cdot \gamma 2_{\theta}\right) + \gamma 2_{\theta}$$

$$s4_{\theta} := \sum_{N} \cos\left(N \cdot \gamma 2_{\theta}\right)$$

$$S5_{\theta} := \sum_{N} \sin\left(-N \cdot \gamma 2_{\theta}\right)$$

Table 1. SFs at Baseband for Three Element Array

Measured SFs	Derived SFs
$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 2\varphi/2$	$\begin{matrix}\cos\\ \sin\end{matrix}\ 0$
$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 3\varphi/2$	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ \varphi/2$
$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 5\varphi/2$	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 2\varphi/2$
	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 3\varphi/2$
	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 4\varphi/2$
	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 5\varphi/2$
	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 6\varphi/2$
	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 7\varphi/2$
$\varphi = \dfrac{2\pi D}{\lambda}$	$\begin{matrix}\pm\cos\\ \pm\sin\end{matrix}\ 8\varphi/2$

Table 2. SFs at 1F for Three Element Array

Measured SFs	**Derived SFs**
$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 2\varphi/2$	$\substack{\cos\\ \pm\sin}\ \omega t$
$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 3\varphi/2$	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ \varphi/2$
$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 5\varphi/2$	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 2\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 3\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 4\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 5\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 6\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 7\varphi/2$
	$\substack{\pm\cos\\ \pm\sin}\ \omega t\ \substack{\cos\\ \sin}\ 8\varphi/2$

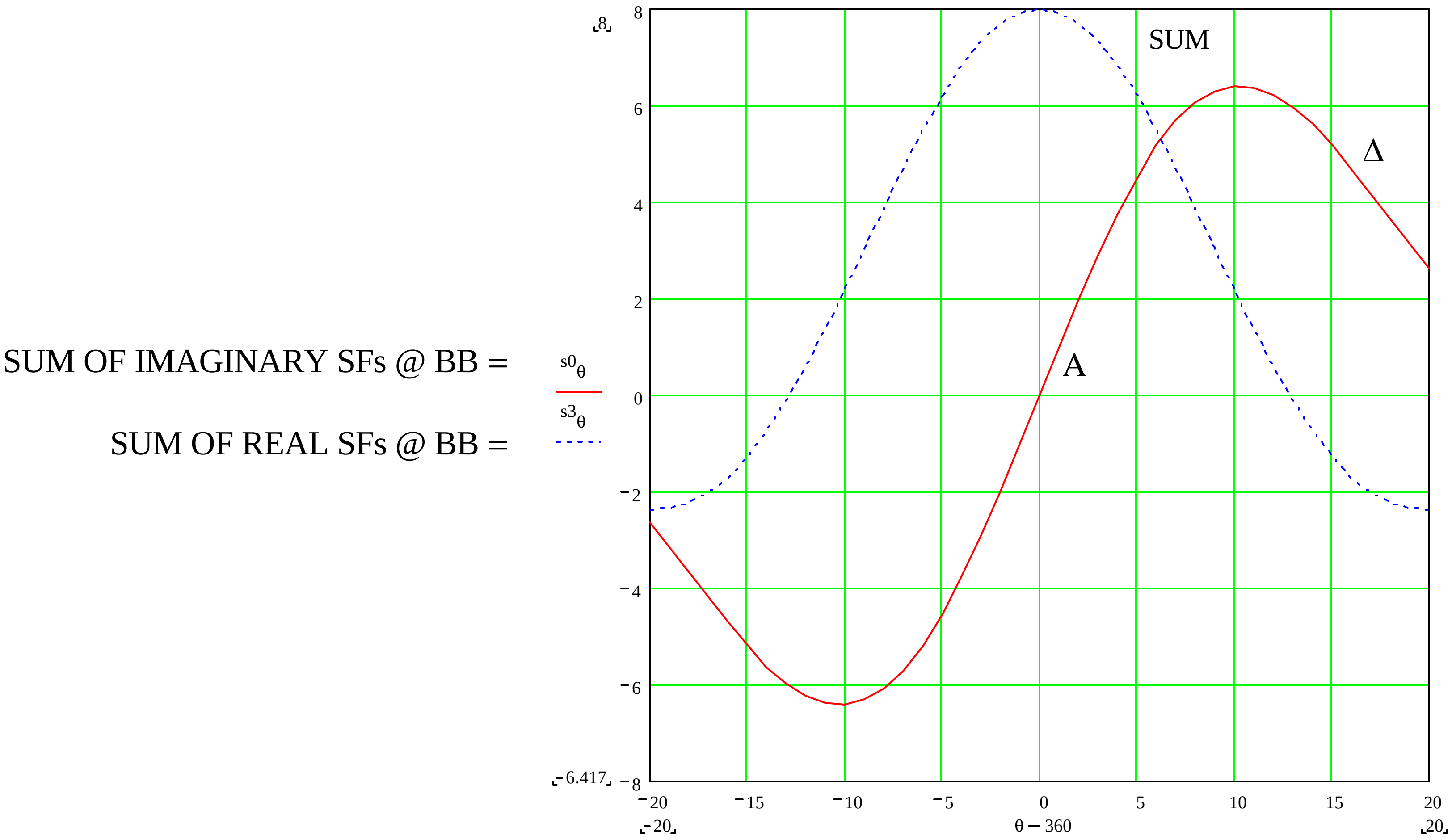

Figure 1. Sum and Error Patterns at BB for 3 Element Array – Single Signal

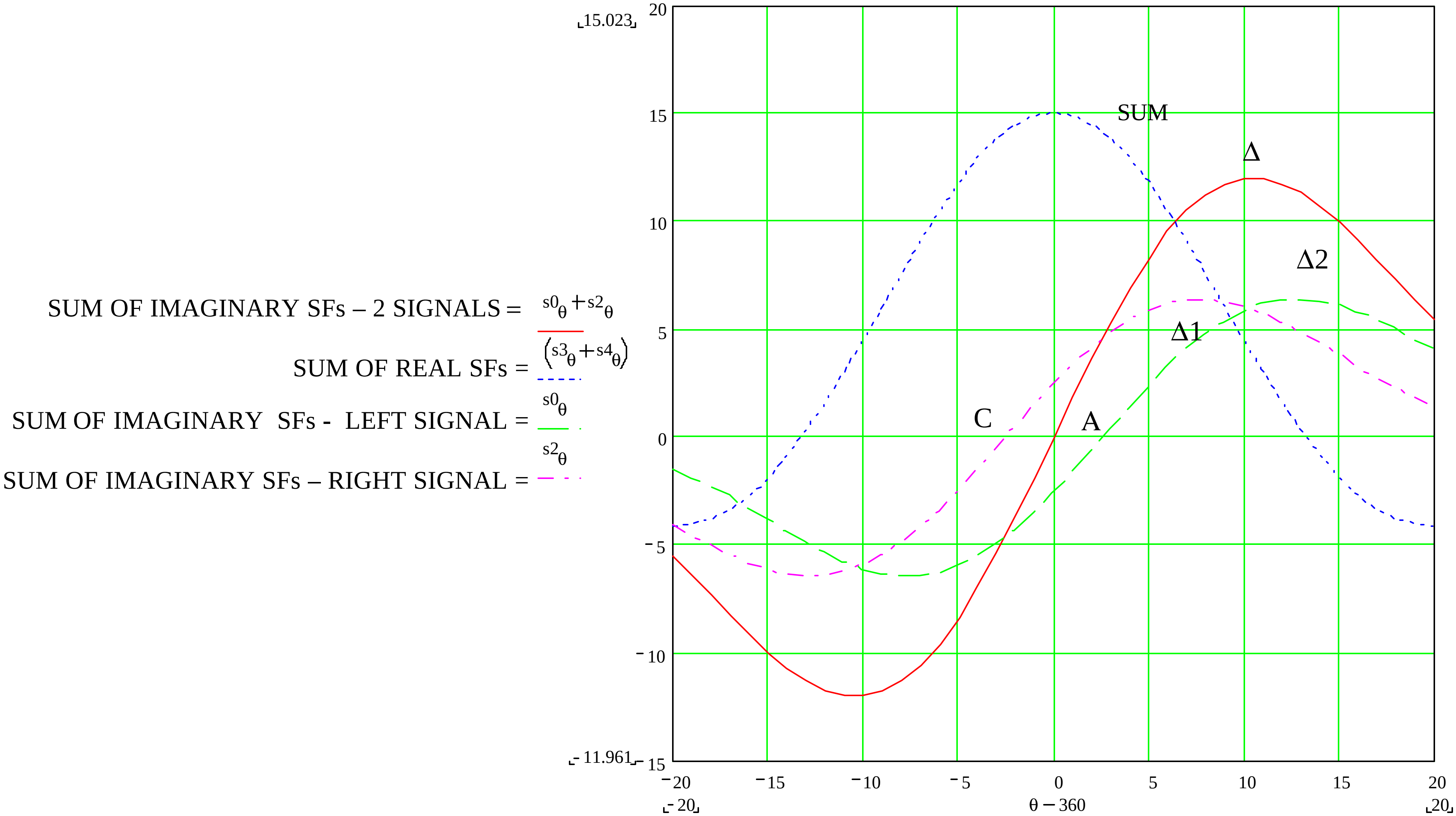

Figure 2. Sum and Error Patterns at BB for 3 Element Array – Two Signals

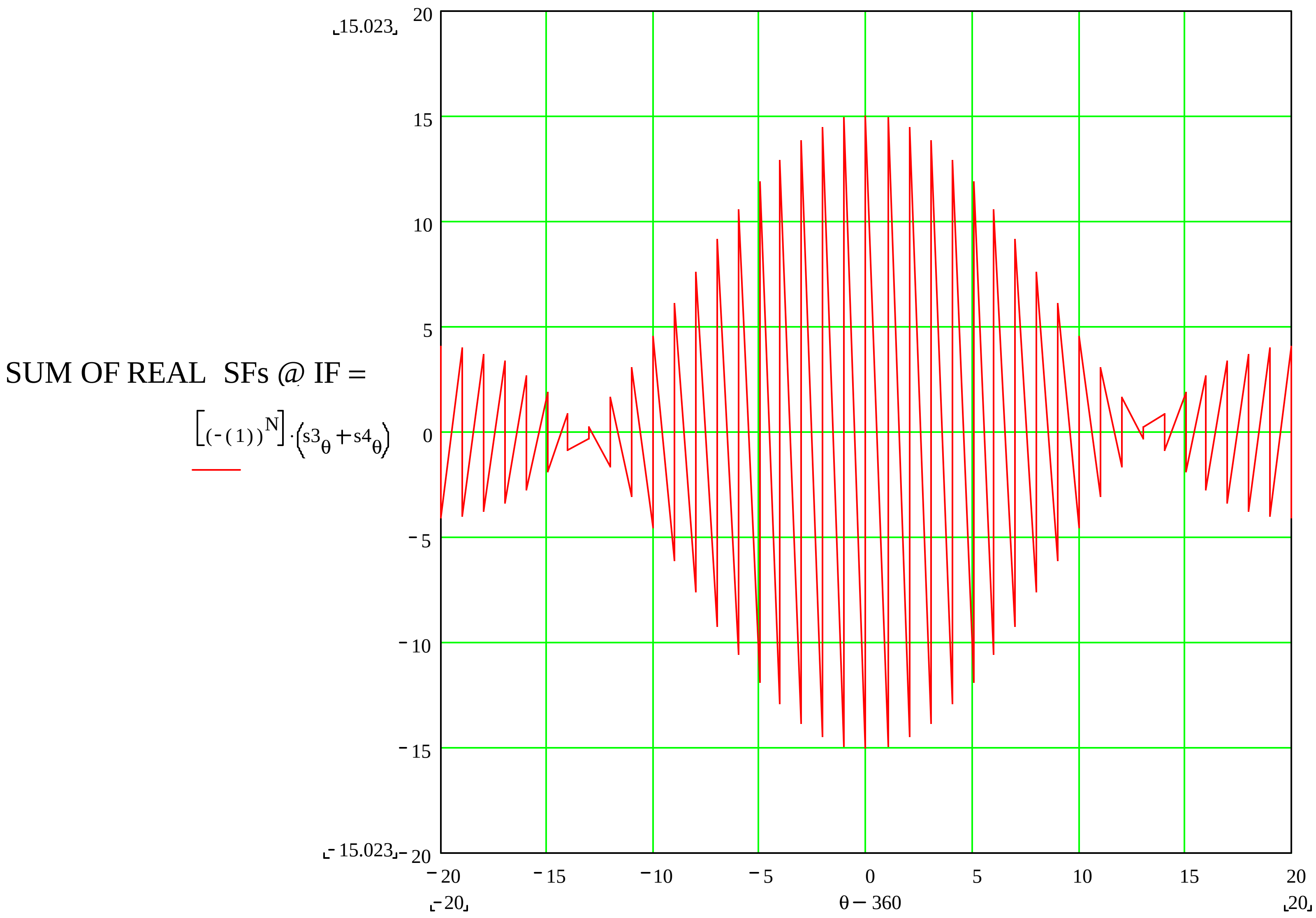

Figure 3. Sum Pattern of Real SFs at IF for 3 Element Array

SUM OF IMAGINARY SFs @ IF =

$$\left[(-(1))^{N}\right]\cdot\left(s0_{\theta}+s2_{\theta}\right)$$

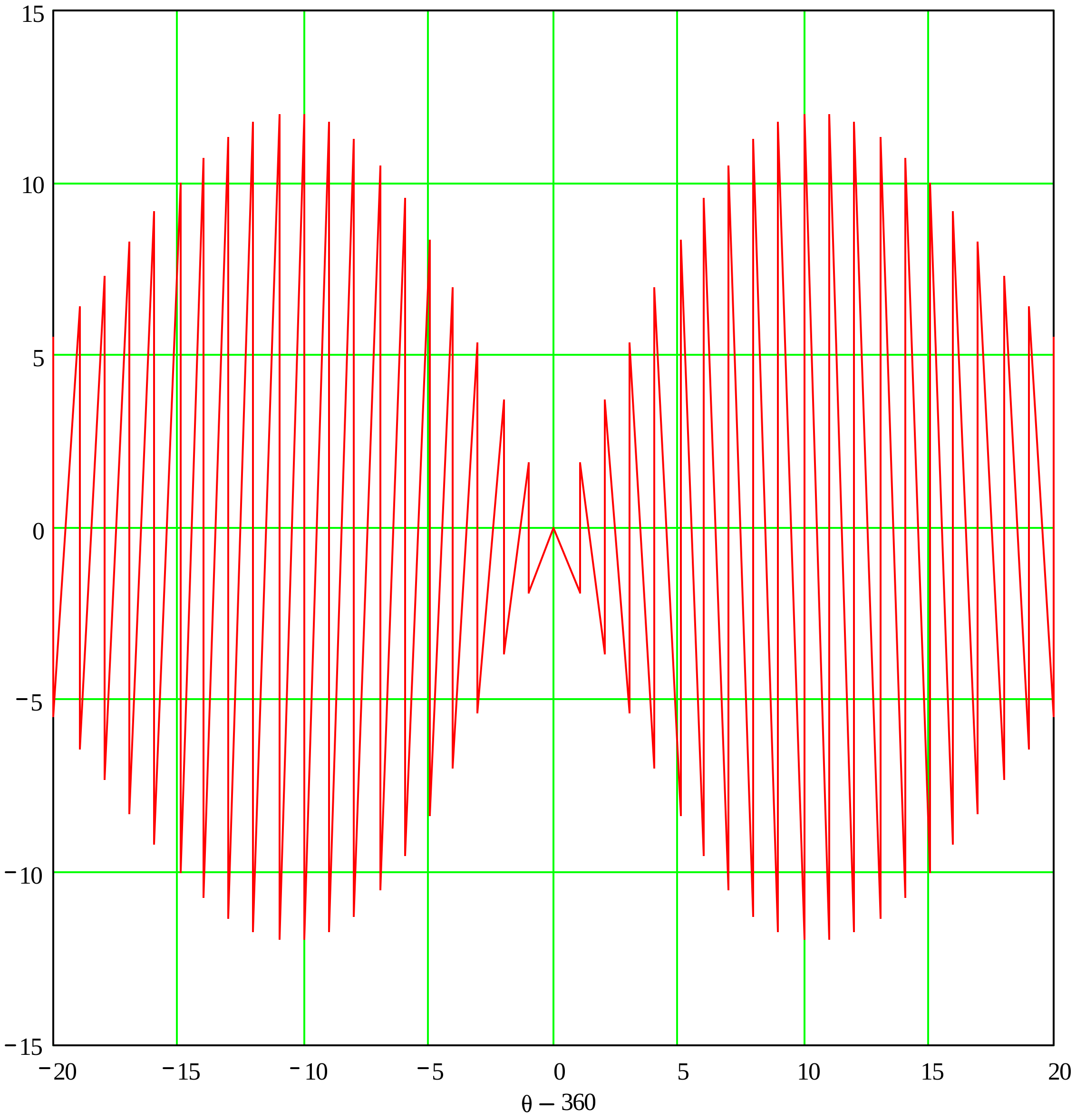

Figure 4. Error Pattern at IF for 3 Element Array