Magnetron Theory of Operation:

Frequency Agile Magnetrons

Frequency agility (FA) in regard to radar operations, is defined as the capability to tune the output frequency of the radar with sufficient speed to produce a pulse-to-pulse frequency change greater than the amount required to effectively obtain decorrelation of adjacent radar echoes.

It has been firmly established that FA, together with appropriate receiver integration circuits, affords reduced target scintillation/glint, improved ability to detect targets in a clutter environment, elimination of 2nd time around echoes, and improved resistance to electronic countermeasures, over that possible with a fixed frequency or tunable radar system. It is important to note that, with the exception of ECM resistance, increasing the pulse-to-pulse frequency spacing will increase the amount of system performance improvement that can be realized to a maximum occurring at the point where full pulse echo decorrelation is obtained (nominally 1/tp). Pulse-to-pulse frequency spacings greater than this critical value produce no further increase in system performance, and, in fact, may result in a performance decrease due to the large "IF" inaccuracies arising from the need for the AFC to correct larger pulse to pulse frequency errors.

On the other hand, as regards resistance to electronic jamming (ECCM), the greater the pulse-to-pulse frequency spacing, the more difficult it will be to center a jamming transmitter on the radarfrequency to effectively interfere with system operation.

Each radar system application must be considered separately to determine which FA parameters will best satisfy the particular need. Just as the FA requirements of each radar differ, so also do the mechanisms differ for optimally producing the required agility parameters. No single tuning scheme has been found which will universally satisfy the requirements of every FA application.

For this reason, CPI EDB produces a broad range of FA tuning mechanisms for coaxial magnetrons; each mechanism offering the optimum combination of parameters for a particular application.

Frequency Agile Magnetron Classes

Frequency agile magnetrons fall into four classes:

- **Dither Magnetrons (D)** -- Output RF frequency varies periodically with a constant excursion, constant rate and a fixed-center frequency.
- **Tunable/Dither Magnetrons (T/D)** -- Output RF frequency varies periodically with a constant excursion and constant rate.The center frequency may be slowly tuned by hand or by external servomotor drive to any point within the tunable band.
- **Accutune(tm) Magnetrons (A)** -- Output RF frequency variations are determined by the waveshape of an externally generated, low level, voltage signal. With appropriate selection of a tuning waveshape, the Accutune magnetron combines the features of dither and tunable/dither magnetrons.
- **Accusweep(tm) Magnetrons (As)** -- Our best and most versatile tuning system. The output RF tuning rate and waveshape are infinitely variable within the design limits of each device. Customer inputs are typically any waveform from random to square wave and a + 5 volt command.

All CPI EDB frequency-agile magnetrons provide a reference voltage output which is an accurate analog of the instantaneous RF output frequency. This signal greatly simplifies automatic frequency control of the system local oscillator frequency. The analog voltage is produced either by a self-generating, permanent magnet device requiring no external drive, or by a precision resolve or LVDT (Linear Voltage Displacement Transducer) acting in conjunction with one of CPI EDB's solid-state frequency readout modules.

The Accutune and Accusweep magnetrons operate with a servo loop, feedback control, tuner drive and thereby utilize CPI EDB's solid-state servo amplifier together with the frequency readout module.

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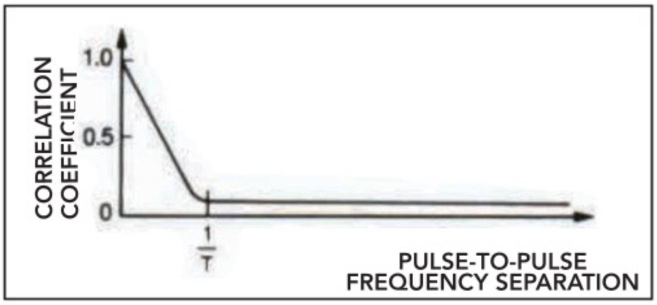
Agile Magnetron Design Considerations

At first glance one might conclude that the largest frequency change at the highest rate will give the best radar performance. Unfortunately, this is not a true statement.

There have been many separate theoretical studies and comprehensive experiments performed to establish the relationship between radar performance improvement and pulse-to-pulse frequency difference. An understanding of the theoretical basis for the conclusions reached in these efforts is important. In order to preserve the continuity of our discussion, we will show only the results of these studies in this section.

Effective performance improvement is achieved when the frequency difference between radar pulses is large enough to eliminate any correlation between the return echoes. A plot of correlation coefficient versus pulse to pulse frequency difference is shown below.



Using this relationship, one finds that a radar operating at a 0.5 µs pulse duration will have efficient decorrelation between target echoes if pulses differ in frequency by at least 2 MHz. Note that the required frequency separation is a function only of the pulse duration.

According to the plot of the figure, as frequency separation increases above the value 1/T, pulse decorrelation continues to improve, however, the amount of improvement is negligibly small for large increases in pulse frequency separation. In practical situations, the improvement in decorrelation obtained by increasing the frequency separation to values greater than 1/T is usually more than offset by other factors. For example, as pulse-to-pulse frequency difference increases, the receiver circuitry needed to assure stable LO (Local Oscillator) tracking also increases, in both complexity and physical size. The accuracy necessary for LO tracking relates directly to the IF bandwidth needed to pass the resultant video signal. Any increase in IF bandwidth, needed to offset inaccuracies in LO tracking, will reduce overall receiver sensitivity and tend to defeat the original purpose. Experience has shown that if one designs for pulse-to-pulse frequency separation as near as possible to, but not le ss than, 1 /T (where T is the shortest pulse duration used in the radar) optimum system performance will be achieved. Experimental studies have shown that performance improvement varies as N, where N is the number of independent (decorrelated) pulses integrated within the receiver circuitry, up to a maximum of 20 pulses.

It should be noted that the number of pulses, which can be effectively integrated, cannot be greater than the number of pulses placed on the target during one scan of the antenna and, therefore, the antenna beamwidth and scan rate become factors which must also be considered in determining the integration period of the radar.

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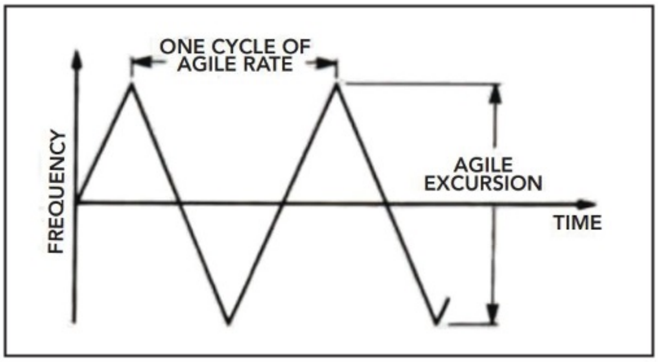
Using the above, a design value for Agile Excursion can now be expressed in terms of radar operating parameters.

Agile Excursion = N/T



Agile Excursion: The total frequency variation of the transmitter during agile operation.

Agile Rate: The number of times per second that

the traansmitter frequency traverses the agile excursion and returns to its starting frequency.

NOTE: There are two excursions of the frequency band for each cycle of agile rate.

Where N is the number of pulses placed on the target during one radar scan, or 20 whichever is smaller, and T is the shortest pulse duration used in the system.

Determination of the required agile rate is now required. The object is to traverse the full agile excursion range in the time needed to transmit the number of pulses on the target during one antenna scan.

Example:

Assume one desires to add agility to a radar having the following operating parameters:

Pulse duration - 0.25, 0.5 & 1.0 µSec.
Duty Ratio - 0.001
Pulses on target - 16 per scan

Using the formulas derived above one obtains:

Agile excursion = N/T = 16/0.25 = 64 MHz
Pulse to pulse frequency separation = 1/T = 1/ 0.25 = 4 MHz
PRR = Duty / T = 0.001/ (0.25x10-6) = 4000 Hz
Time for 16 pulses = 16/ 4000 = 0.004 Sec
Agile Rate* = 1/(2x0.004) = 125 Hz

* The 2 in the denominator accounts for the fact that two excursions through the agile frequency range occur during each cycle of agile rate.

The agile parameters used above were derived using clutter reduction as the prime objective. Elimination of target scintillation requires the satisfaction of one additional constraint, namely that the agile excursion in MHz should be at least equal to 150/D, where D is the characteristic distance, in meters, between major reflecting points on the target cross section. For most practical situations, an excursion which satisfied the requirements of clutter reduction will usually be sufficient to satisfy the requirements of target scintillation also.

Further information and data on agile coaxial magnetrons can be obtained by requesting the Frequency Agile Magnetron Story booklet.