

## Tunable Filter and Multiplexer for Improved Transmitter Electromagnetic Compatibility

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**Introduction:** The challenge of using high-power transmitters, or “jammers,” is complicated by the desire for these transmitters to be compatible with friendly-force systems that operate in the same region of the electromagnetic spectrum. Electromagnetic compatibility is particularly difficult to achieve when practical constraints, such as size, weight, and power, dictate that these transmitters operate efficiently—a mode of operation in which their amplifiers are more prone to generate spurious signals that interfere with friendly-force systems.

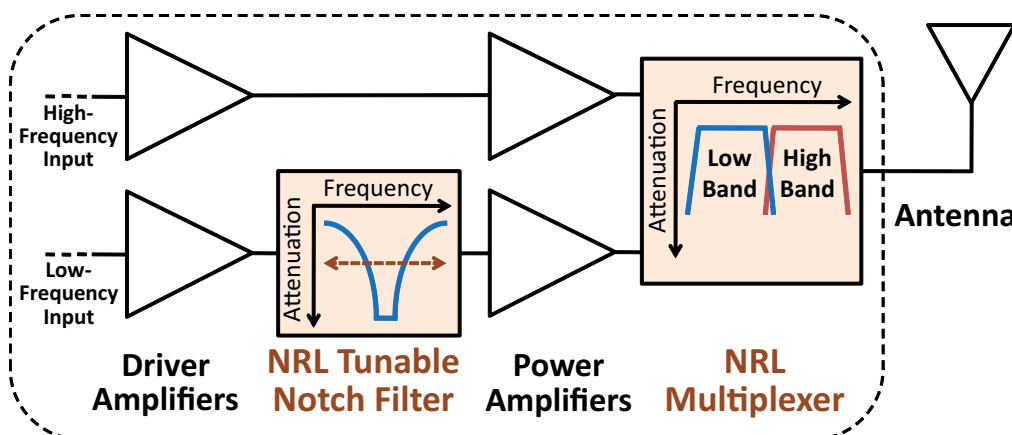
To address the issue of electromagnetic compatibility in transmitters, MITRE Corporation is developing an extensible transmitter architecture that will broadcast less friendly-force interference. MITRE enlisted NRL to develop filters able to suppress interference transmission without compromising the transmitter’s task. Within a four-month time frame, NRL’s Microwave Technology Branch developed a novel high-power contiguous-channel frequency multiplexer for suppression of amplifier second harmonics and a novel microsecond-tunable notch filter for excision of selectable narrow frequency bands from an amplifier’s input. Figure 1 illustrates the integral role of these filters in the transmitter’s output module.

**Ridge-Waveguide Multiplexer:** The multiplexer selectively combines the outputs of two sub-octave-frequency-banded power amplifiers, preserving signal power while suppressing harmonic and other out-of-

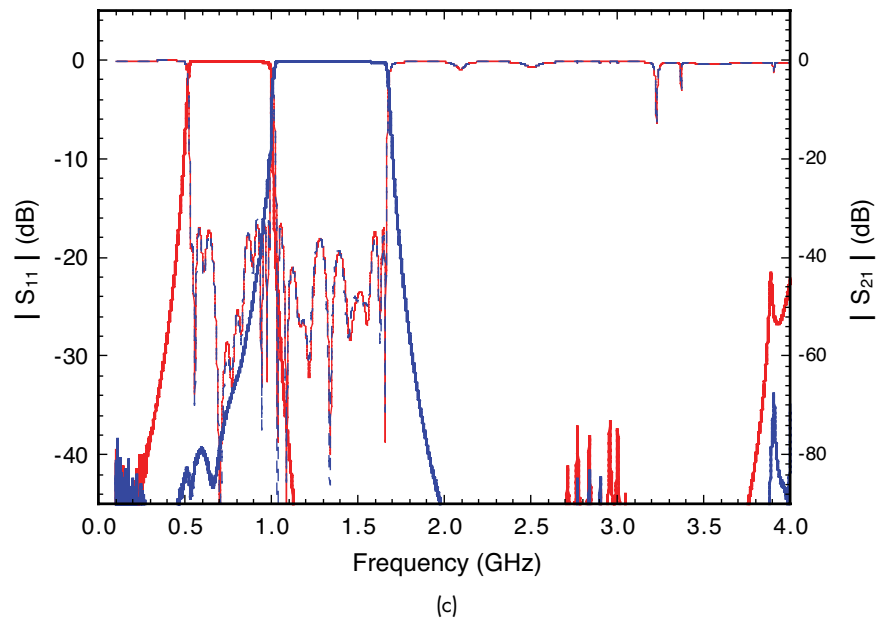
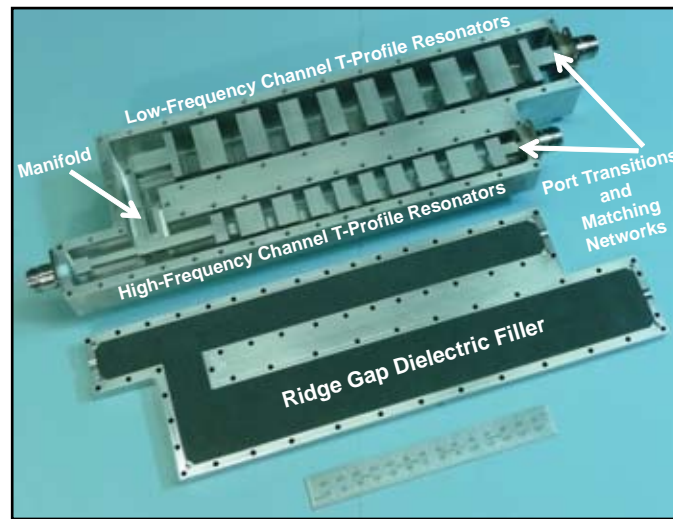
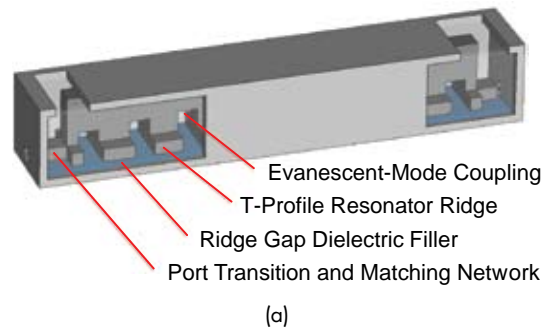
band interference. Composed of two ten-resonator channel filters and a manifold, it was designed using commercial general-purpose electromagnetic-analysis and circuit-simulation software.<sup>1</sup> As shown in Fig. 2(a), each channel filter employs T-profile ridge waveguide, known for its compact size, low passband insertion loss, and wide stopbands. Dielectric fill of the gap between the ridges and opposing waveguide wall lowers the waveguide cutoff frequency and reduces filter size. Notched ridge-waveguide sections create evanescent-mode coupling between adjacent ridge-waveguide resonators for further size reduction.<sup>1</sup> Notch depths are varied to adjust couplings, while widths are kept equal to facilitate manufacturing. As shown by the partially disassembled multiplexer in Fig. 2(b), a coaxial manifold connects channel filters to a common antenna port, inhibiting modes that would degrade stopband performance. N-type connectors are used for convenience, and integrated coaxial-to-ridge-waveguide transitions and port matching networks help to reduce the overall size.

The transmission and reflection characteristics of the 375 mm × 108 mm × 57 mm unplated aluminum multiplexer, with no post-assembly tuning, are plotted in Fig. 2(c). The 531–977 MHz and 1030–1636 MHz channels have less than 0.5 dB insertion loss, and their respective second harmonics are attenuated by more than 60 dB. Compared with conventional approaches, this new multiplexer technology enables substantial savings in size while retaining excellent electrical performance, power handling, and manufacturability. The approach to design and realization appears accurate enough that post-assembly tuning will not be needed, further reducing cost and improving reliability.

**Tunable Microstrip Notch Filter:** The tunable notch filter selectively removes jamming energy in a



**FIGURE 1**  
Simplified functional block diagram of MITRE’s experimental transmitter output module, including NRL’s two-channel multiplexer and tunable notch filter.

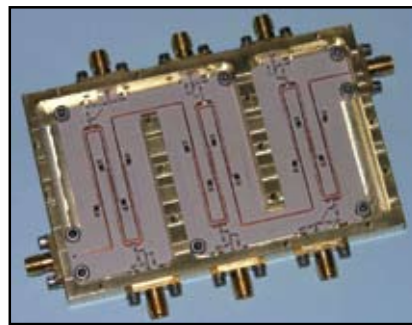
**FIGURE 2**

(a) A partial cutaway rendering of a single ridge-waveguide channel filter, together with (b) a photo of the 531–1636 MHz, partially disassembled, two-channel ridge-waveguide frequency multiplexer and (c) a plot of the multiplexer's measured transmission and reflection characteristics.

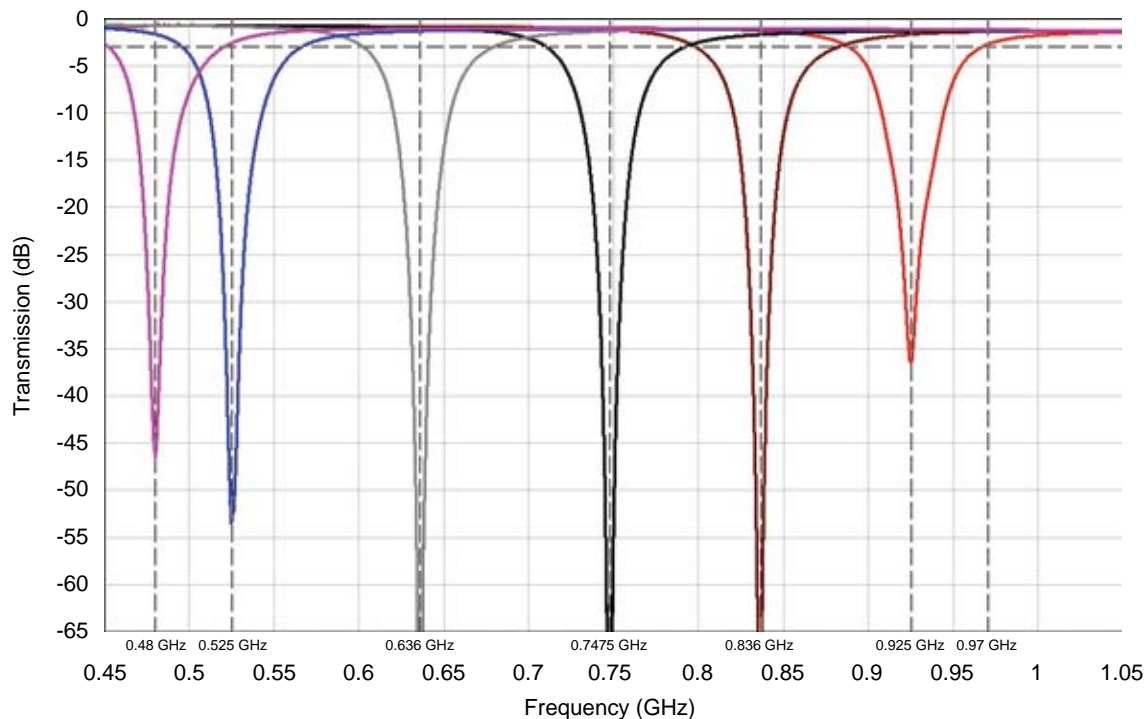
selectable frequency band before it can be amplified and broadcast, enabling equipment interoperability through a new level of control over transmitted spectral content. MITRE's requirement for sub-microsecond tunability of a narrow 60 dB stopband over nearly an octave frequency range cannot be met with conventional reflective notch filters, in which resonator resistance limits stopband attenuation and selectivity, especially with the added resistance of semiconductor frequency-tuning elements. However, the requirement can be met with absorptive notch filter technology<sup>2,3</sup> recently developed at NRL, in which resonator and associated tuning element resistance limits minimum 3-dB bandwidth rather than stopband attenuation. Within the stopband, signal power not reflected is dis-

sipated in the resistance of resonators and their tuning elements, enabling theoretically infinite attenuation. And while changes in operating frequency correspond with commensurate changes in couplings and tuning-element resistance that degrade the performance of conventional notch filters, absorptive notch filters can correct for these commensurate changes with a simple offset between the tuned frequencies of coupled pairs of resonators, enabling stopband attenuation and bandwidth to be preserved across a broad range of operating frequencies.

The 102 mm × 64 mm × 9 mm microstrip absorptive notch filter, comprised of a cascade of three two-resonator absorptive notch sub-circuits, is shown in Fig. 3 with its measured performance. Using com-



(a)



(b)

**FIGURE 3**

(a) Photograph and (b) measured transmission characteristic of the sub-microsecond-tunable microstrip absorptive notch filter with a 480–925 MHz (or more than 92%) tuning range, tuned to six different operating frequencies: 480, 525, 636, 747.5, 836, and 925 MHz.

mercial hyperabrupt varactor diodes as tuning elements, the filter maintains a 3-MHz-wide stopband attenuation of more than 60 dB across a majority of its 480–925 MHz tuning range. Passband insertion loss ranges from 0.7 dB to 1.2 dB, 3-dB bandwidth remains less than 84 MHz while varying less than 24% over the tuning range, and, thanks to 100-MHz-bandwidth lowpass bias networks, transition time from one 60-dB-attenuation operating frequency to another is 720 ns. The filter achieves an unprecedented combination of frequency tuning range and speed, electrical performance, and size using only inexpensive, commercially available materials and components.

**Summary:** NRL developed two critical, novel components for insertion into a new MITRE transmitter architecture: a multiplexer and a tunable notch filter, both having small size, low cost, and good performance. The success of MITRE's subsequent transmitter demonstration suggests a practical near-term path to improved equipment compatibility and interoperability, and supports the Navy's near-term equipment acquisition plans by showing the feasibility of demanding Navy requirements and by serving as a design reference for industry.

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[Sponsored by NAVSEA]

#### References

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- <sup>2</sup>D.R. Jachowski, "Compact, Frequency-agile, Absorptive Bandstop Filters," *2005 IEEE MTT-S Int. Microwave Symp. Dig.*, 513–516 (2005).
- <sup>3</sup>D.R. Jachowski, "Narrow-band Absorptive Bandstop Filter with Multiple Signal Paths," U.S. Patent No. 7,323,955, January 29, 2008.