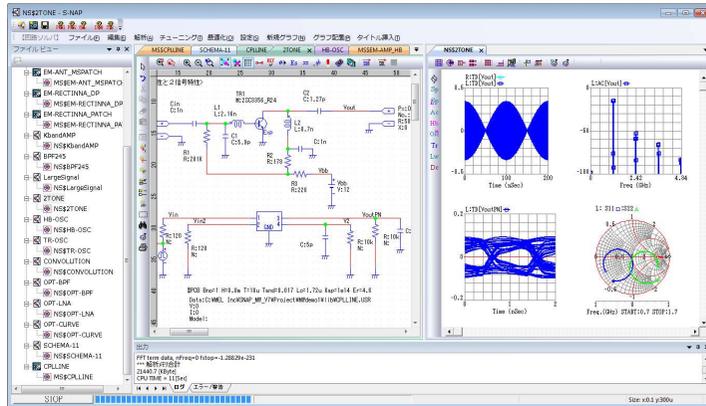

3次元モーメント法電磁界シミュレータを用いた、
ワイヤレス電力伝送、組み込みアンテナ、3DEMC問題の解析事例の紹介

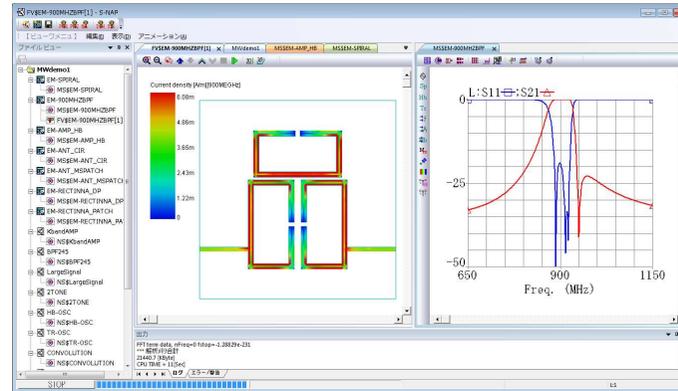
2018年11月 MWE2018
株式会社 エム・イー・エル



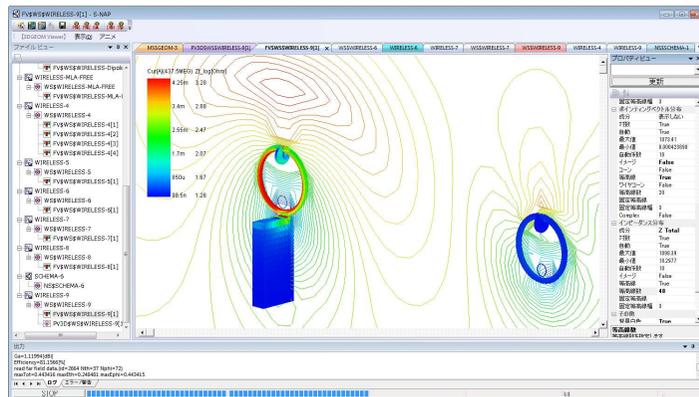
S-NAP Wireless Suiteの概要



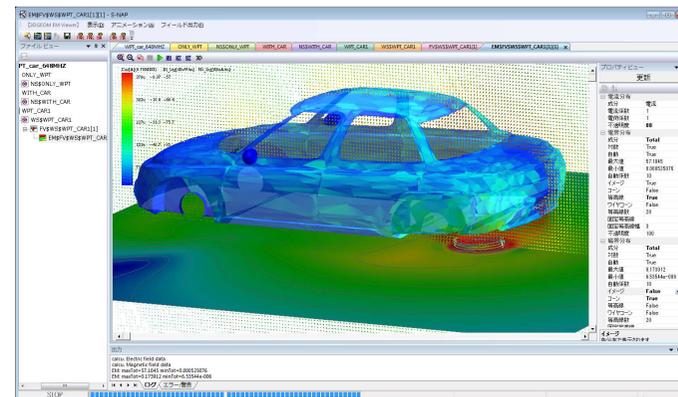
回路解析



多層基板電磁界解析



3次元電磁界解析



3次元モーメント法電磁界

$$\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + j\omega\epsilon\mathbf{E}$$

マクスウエルの方程式



$$\nabla^2 \mathbf{E} + k^2 \mathbf{E} = j\omega\mu\mathbf{J}$$

ヘルムホルツ波動方程式



$$E_k(\mathbf{r}) = -j\omega A_k(\mathbf{r}) - \nabla\phi_k^e(\mathbf{r}) - \frac{1}{\epsilon_k} \nabla \times F_k(\mathbf{r})$$

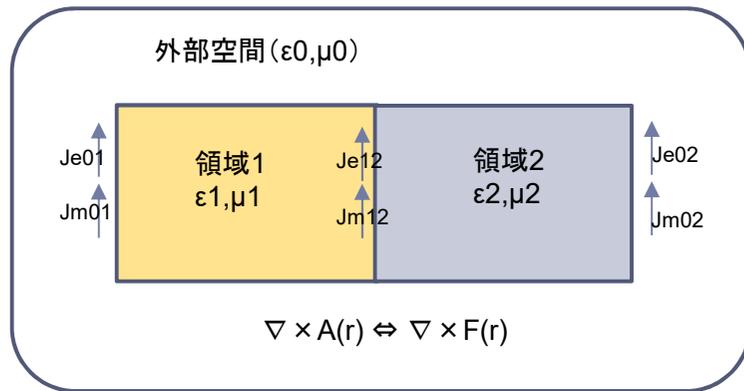
ここで、

$$A_k(\mathbf{r}) = \mu_k \iint_S G_k(\mathbf{r}, \mathbf{r}') J_{e,k}(\mathbf{r}') d\mathbf{r}'$$

$$F_k(\mathbf{r}) = \epsilon_k \iint_S G_k(\mathbf{r}, \mathbf{r}') J_{m,k}(\mathbf{r}') d\mathbf{r}'$$

$$\phi_k(\mathbf{r}) = 1/\epsilon_k \iint_S G_k(\mathbf{r}, \mathbf{r}') q_{e,k}(\mathbf{r}') d\mathbf{r}'$$

k:領域番号



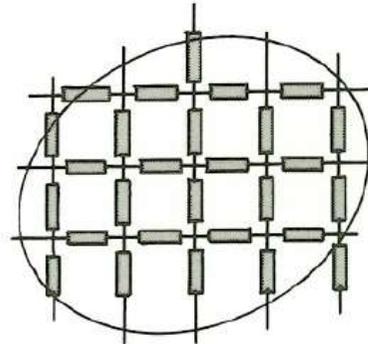
積分形の解

MPIE(Mixed Potential Integral Equation)

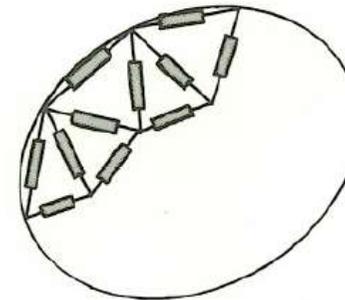
電磁界解析手法のおおまかな分類

▶ 差分法
(FDTD,TLM法)

▶ 有限要素法



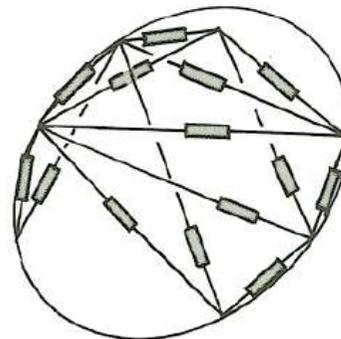
(a) 差分モデル



(b) 有限要素モデル

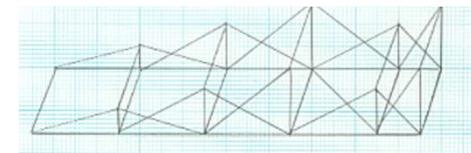
▶ 境界要素法

▶ (モーメント法)

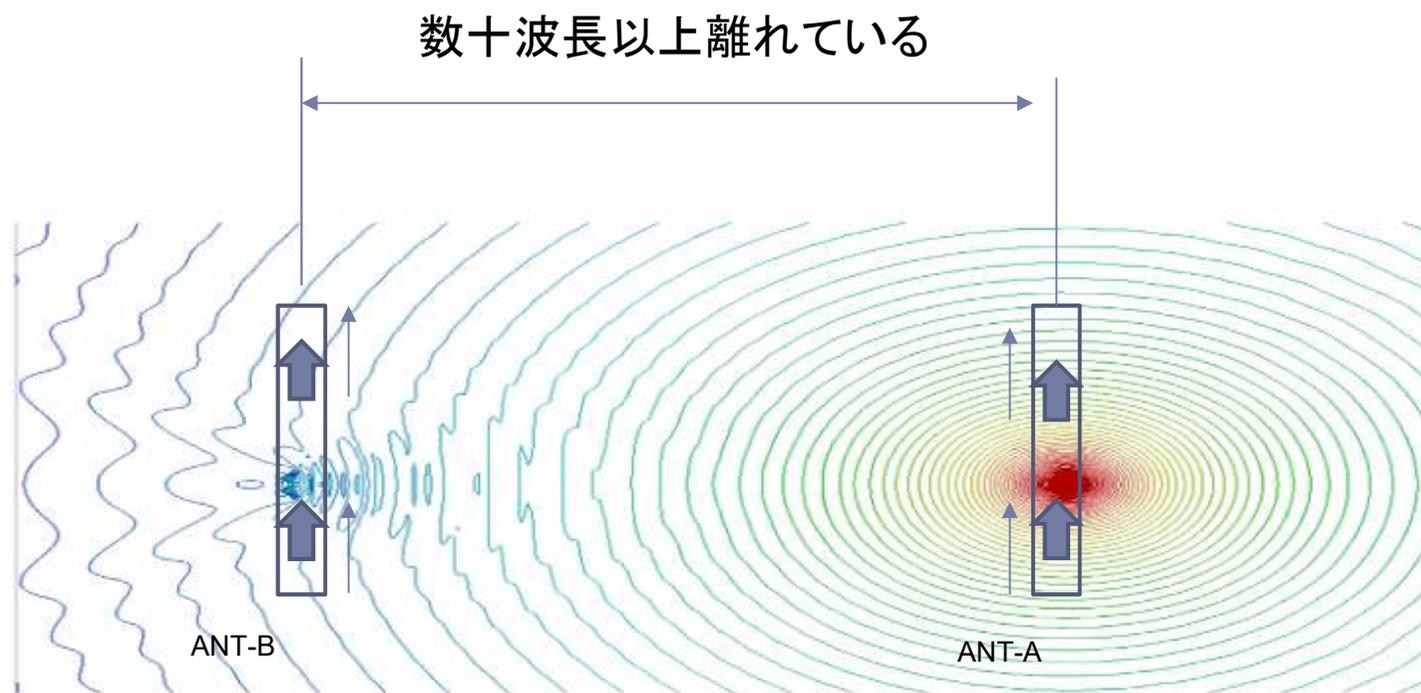


(c) 境界要素モデル

モーメント法は、積分方程式の解を既知の展開関数の線形結合として解く手法。

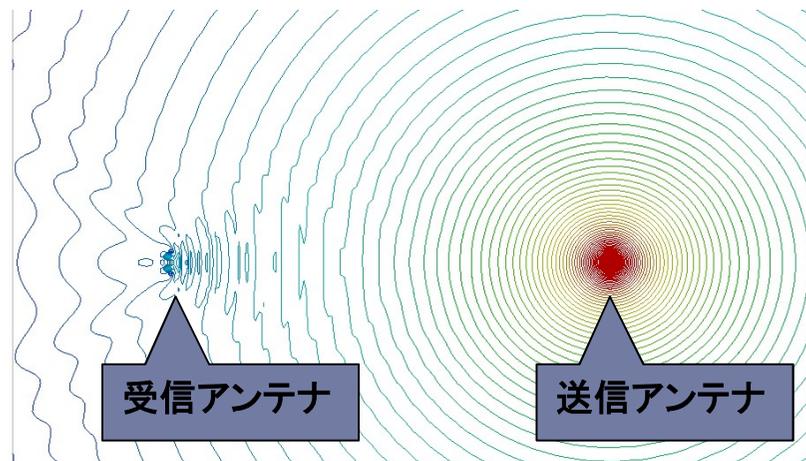
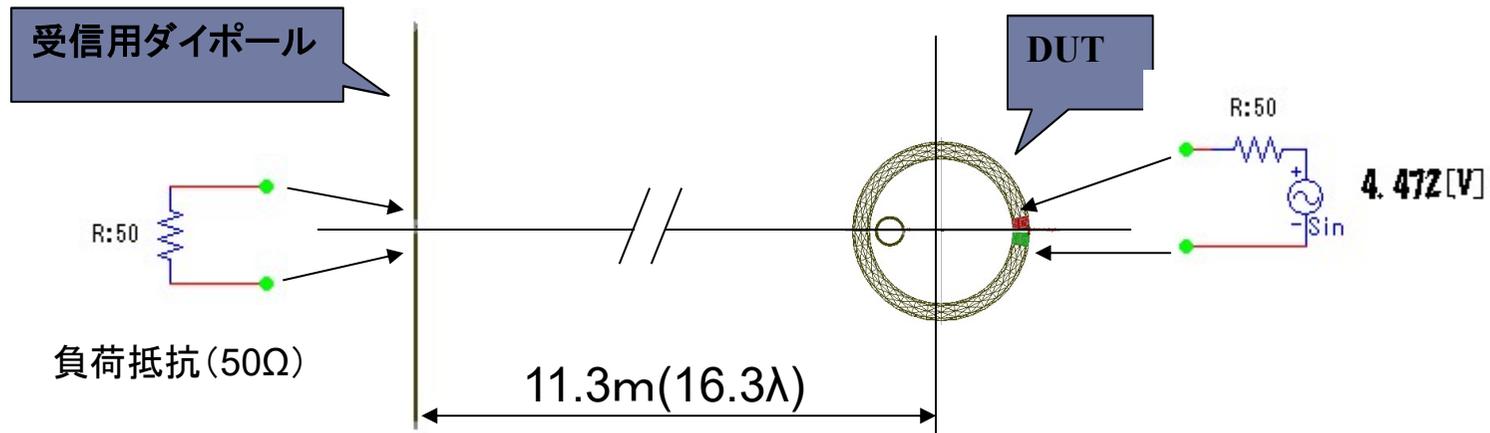


特長 1 : 超遠方特性の解析



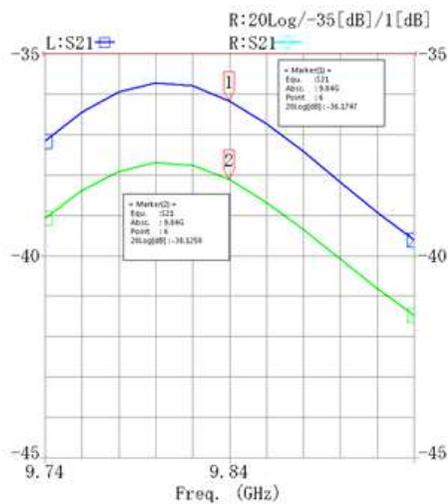
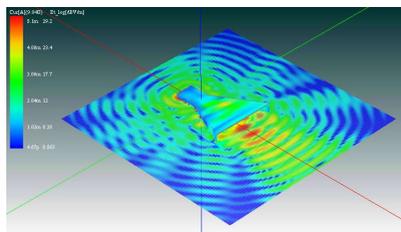
アンテナ誘起電力の実測比較

DUTに励振した場合の、ダイポールの負荷抵抗の電力をシミュレーション @435MHz
・励振電力:100mW

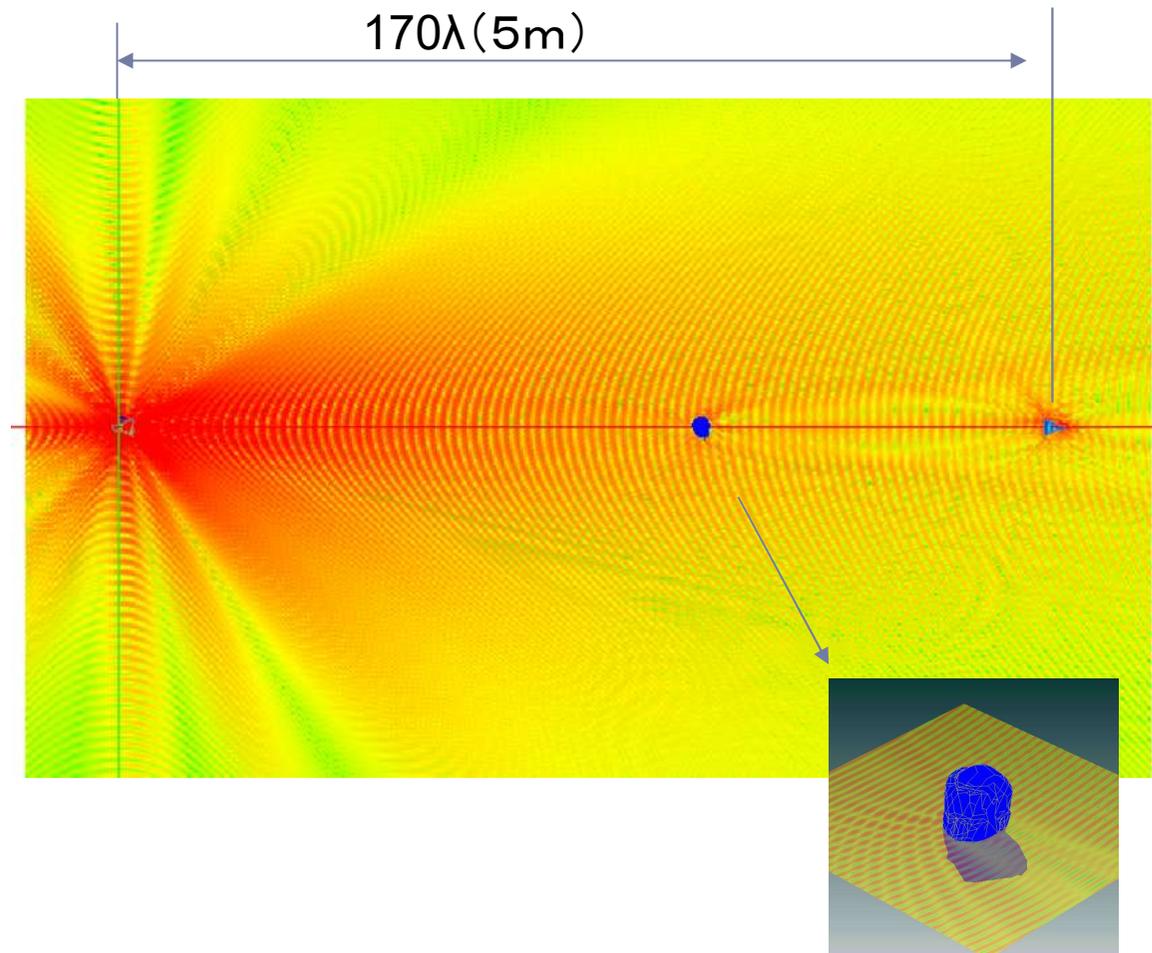


DUT	計算値 [dBm]	実測値 [dBm]
MLA	-25.04	-25.0

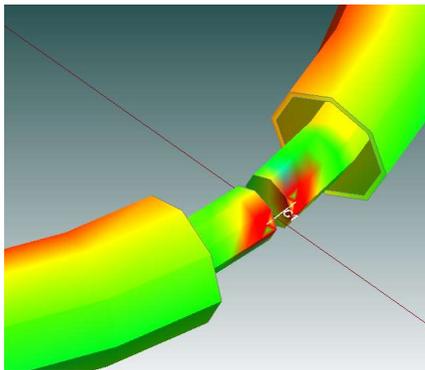
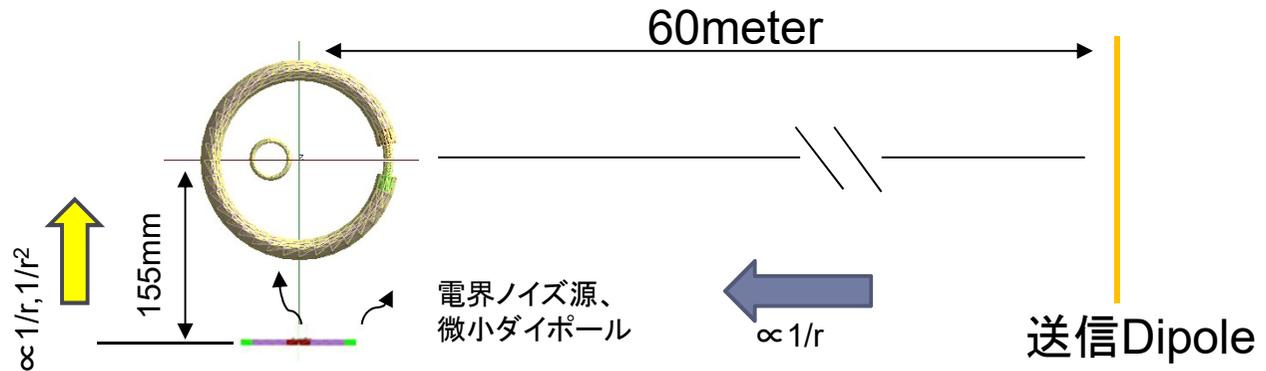
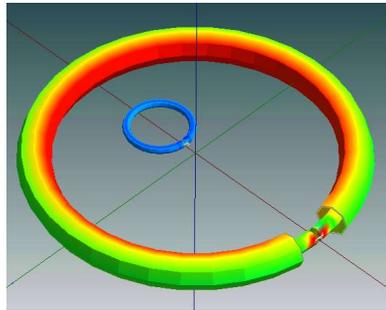
ホーンアンテナ間に人体頭部が置かれた場合の伝搬特性 (10GHz)



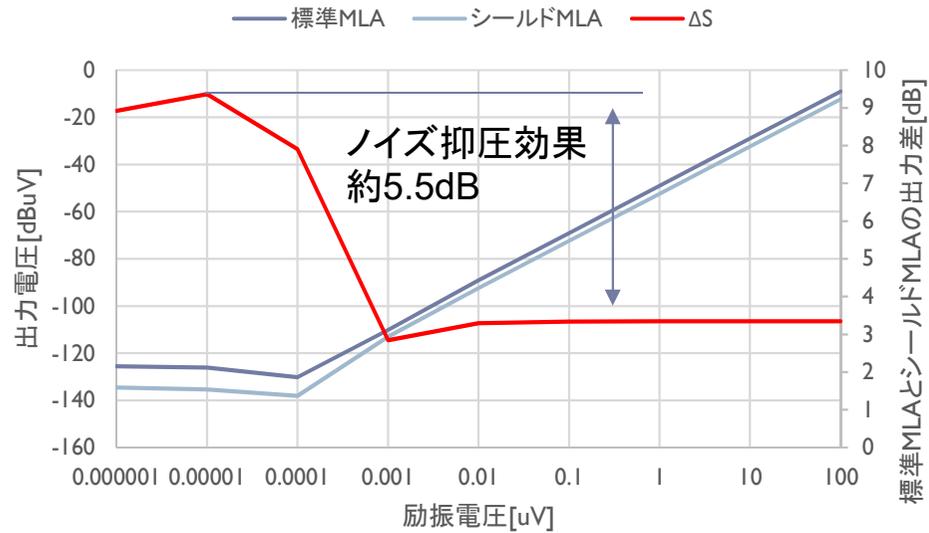
Obstacle有り無しでのS21



アンテナのノイズ特性の解析

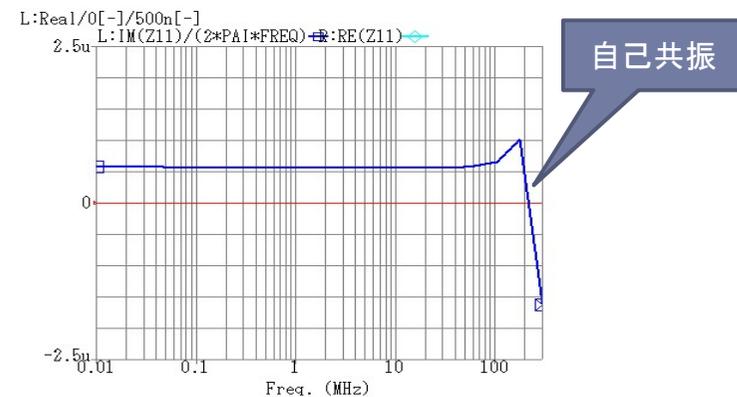
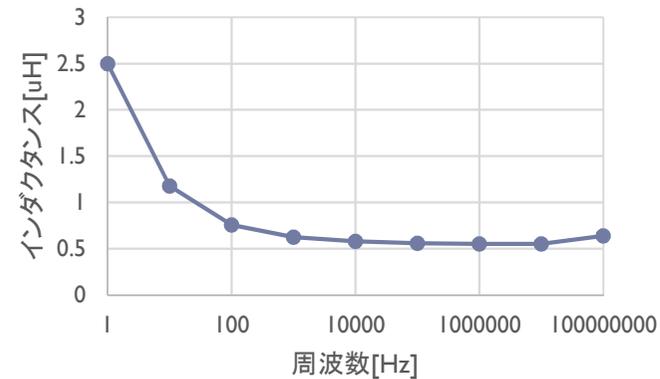
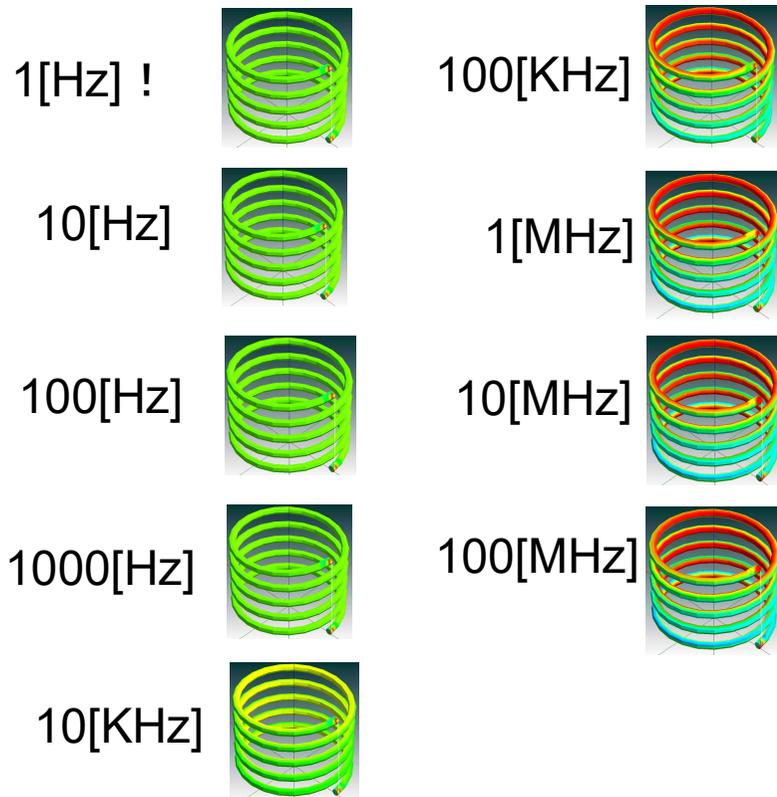


シールド開口部

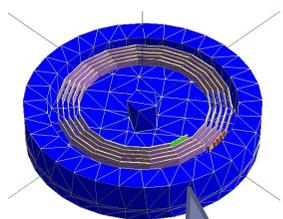


特長 2 : 低周波領域の解析

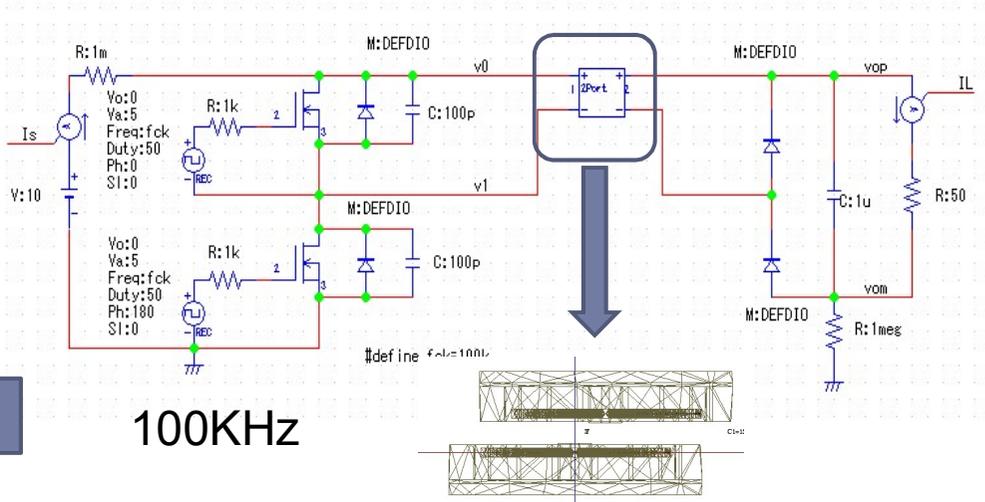
MPIE法は、1次変数に電流密度と電荷密度を用いることで、非常に低い周波数から安定して解析が可能にしています。以下は極端な例ですが、1Hz~100MHzまでの解析例です。



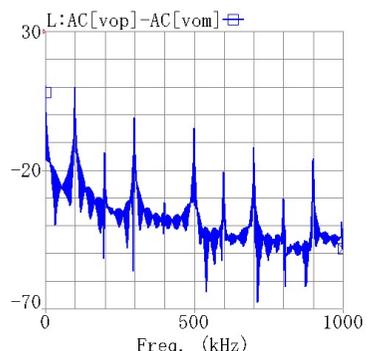
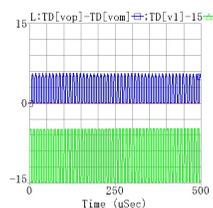
電磁誘導方式の電力伝送解析 (100KHz)



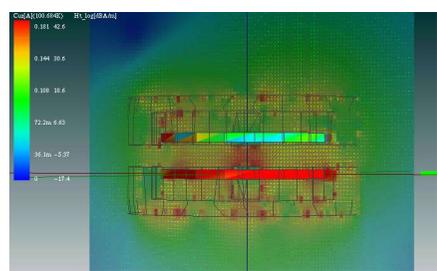
フェライト



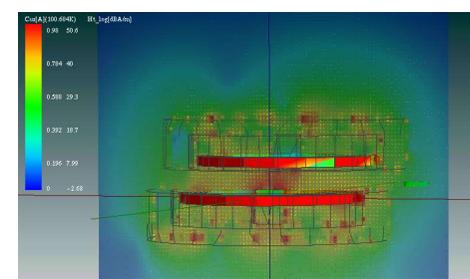
100KHz



出力スペクトル



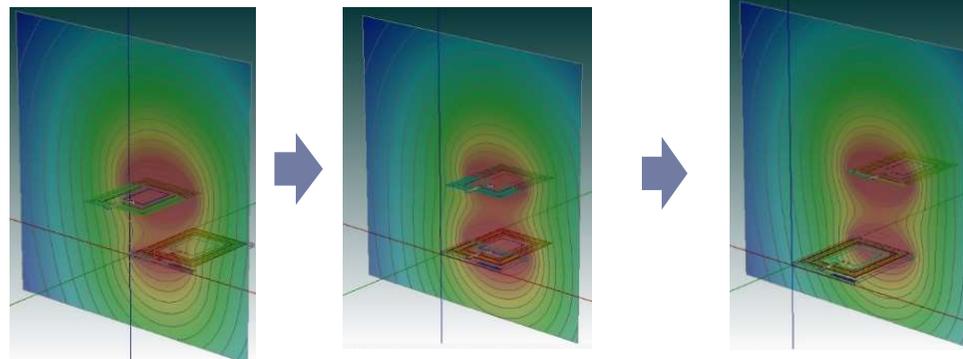
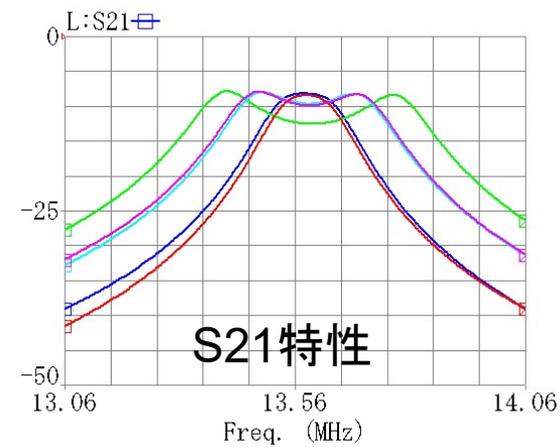
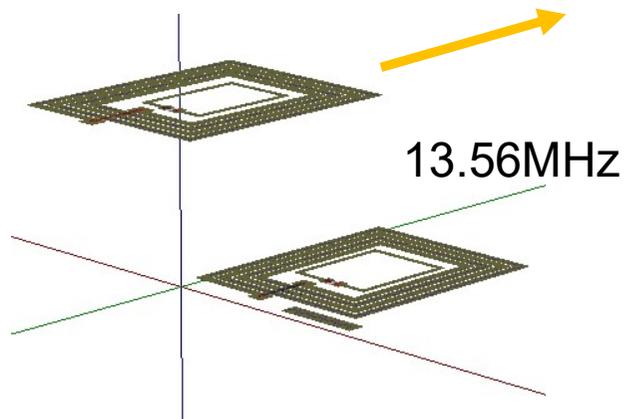
オフセット無し



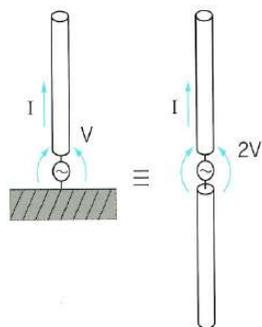
オフセットあり

IDカードシミュレーション(13.56MHz)

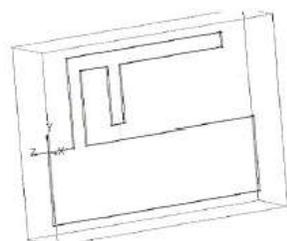
- ・IDカードが親機の真上に来ると強結合になり双峰特性になる
- ・他のカードを読まないように気を付ける



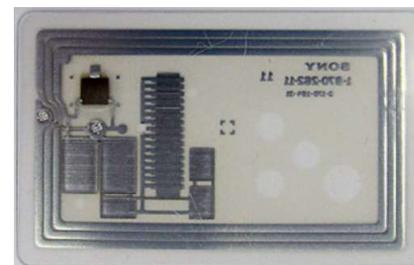
アンテナの種類



モノポール, ダイポール



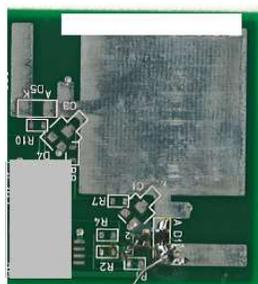
逆Fアンテナ



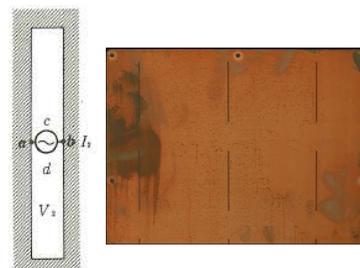
13.56MHz



50MHz



2.45GHzパッチ
アンテナ



(1) スロットアンテナ

2.45GHzスロツ
トアンテナ

電界型アンテナ



315MHz

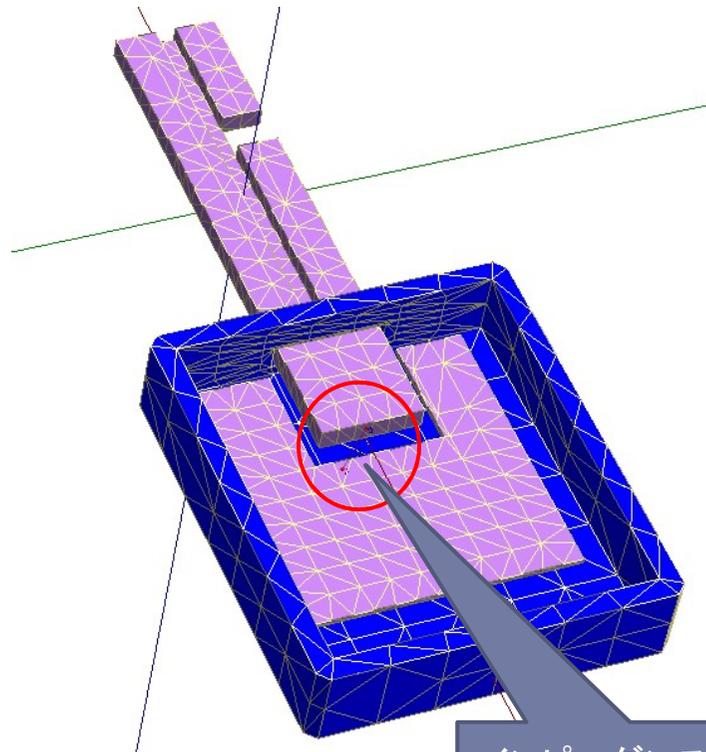


435MHz

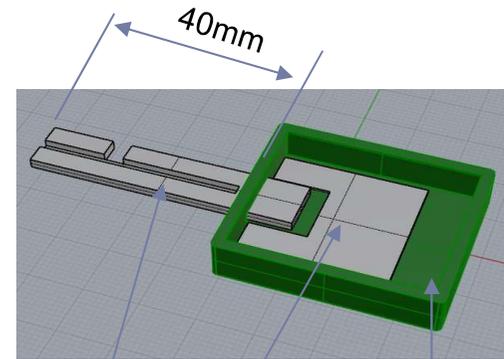
磁界型アンテナ

電界型小型アンテナ (315MHz)

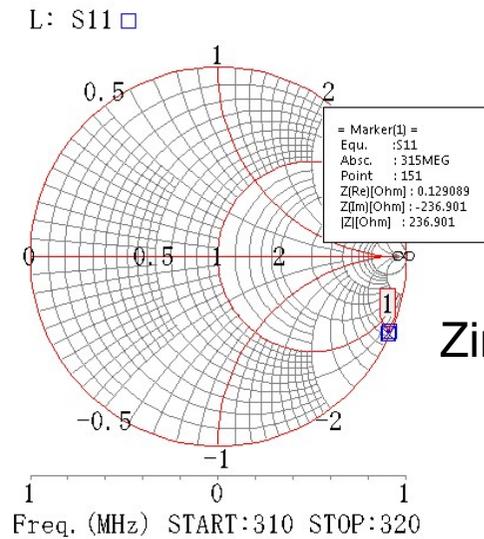
約40mmの金属鍵部を持つキーを315MHzのワイヤレス化する場合のアンテナ設計例



インピーダンスを調べる

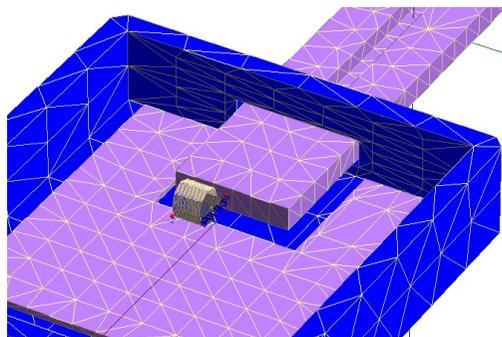


アンテナ グランド板 樹脂ケース

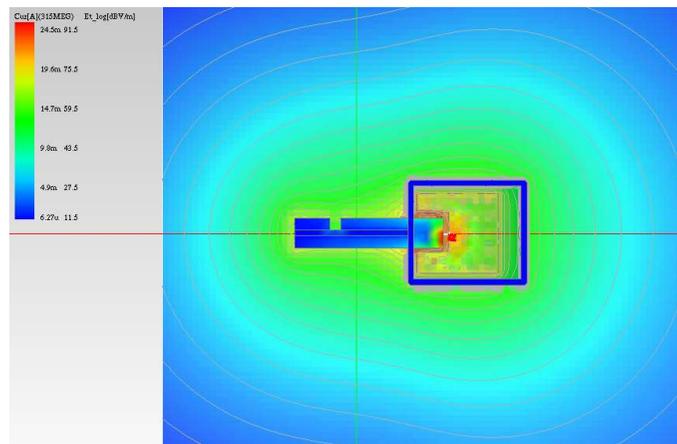
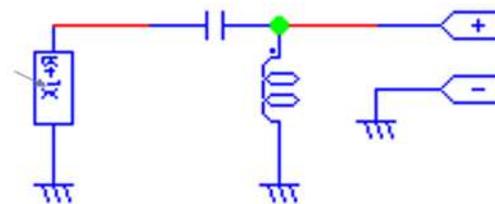


$Z_{in}=0.13-j236[\Omega]$

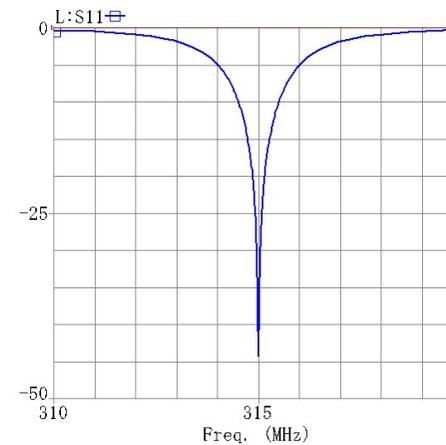
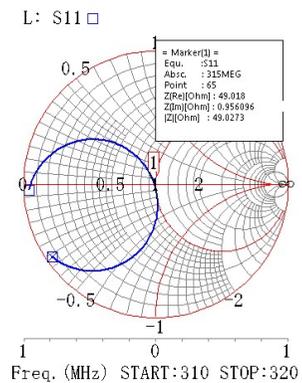
整合回路を付ける



+

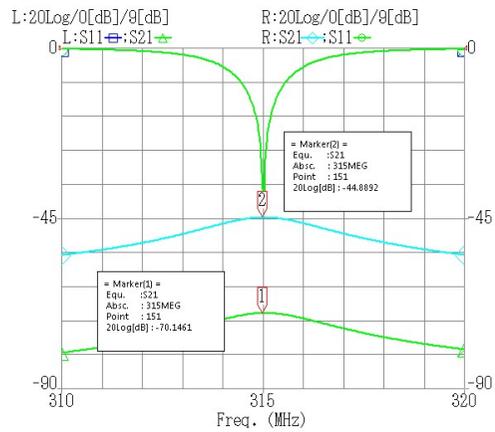
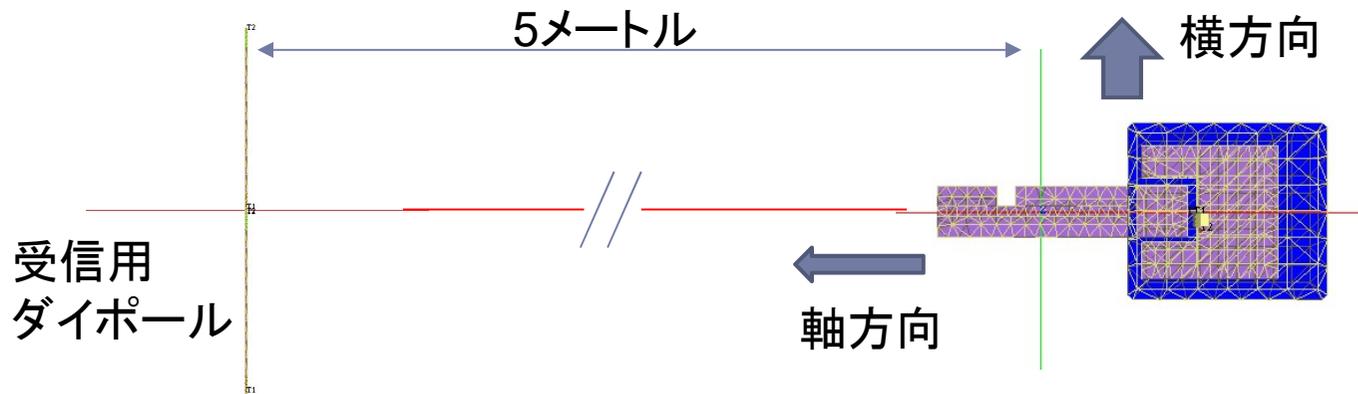


近傍電界

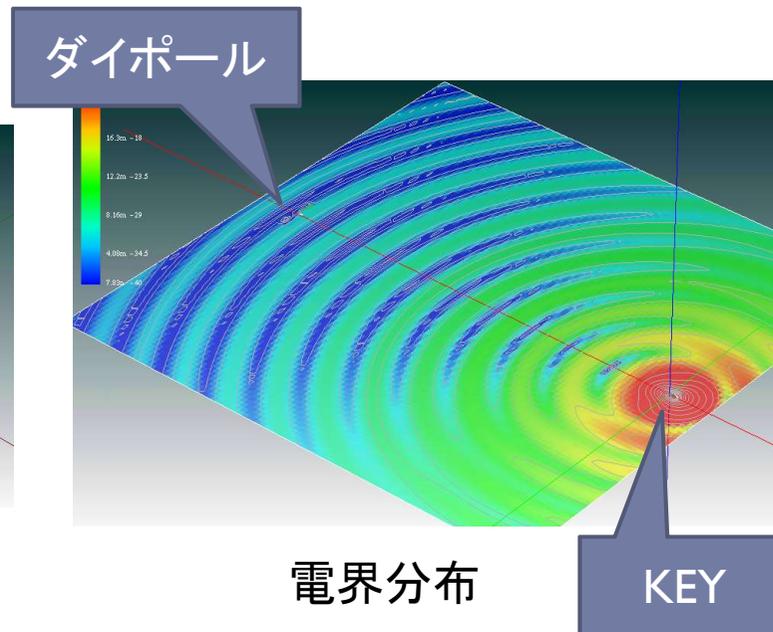
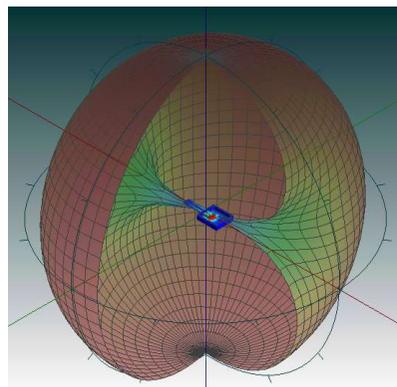


315MHzで整合の取れたアンテナができる

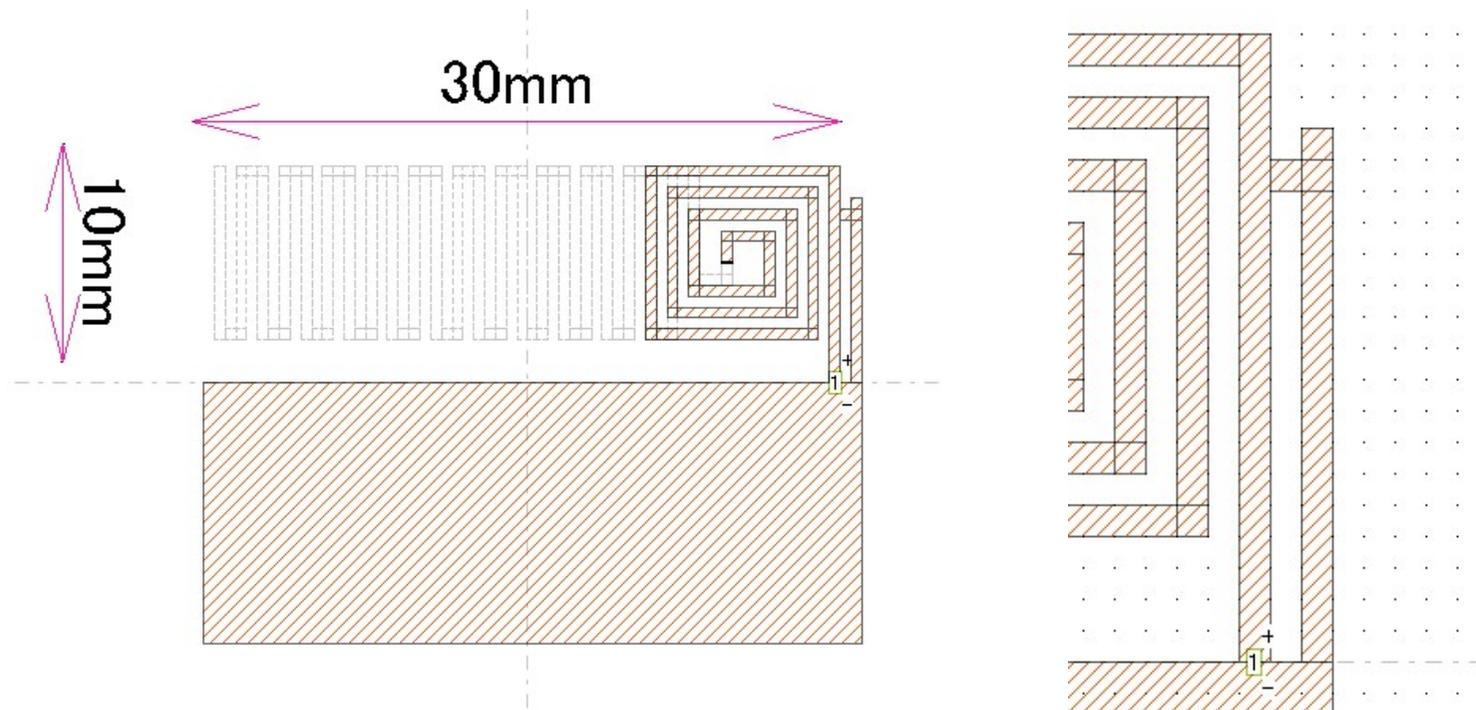
到達距離を調べる



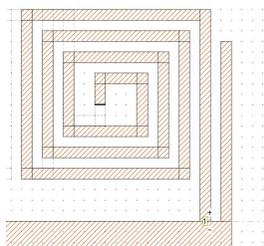
S21=-70dB 軸方向
S21=-45dB 横方向



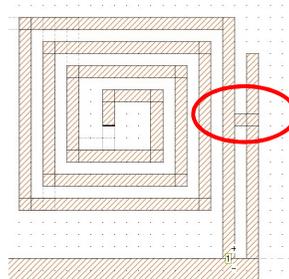
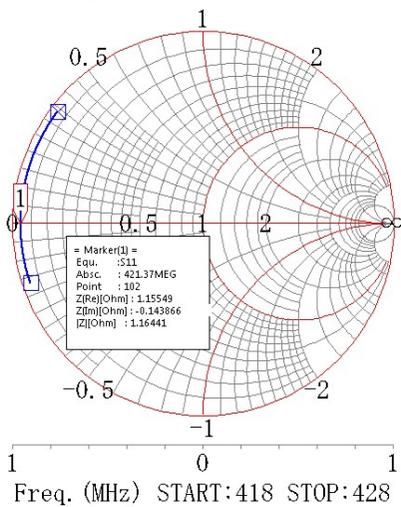
UHF帯 (425MHz) プリントアンテナ



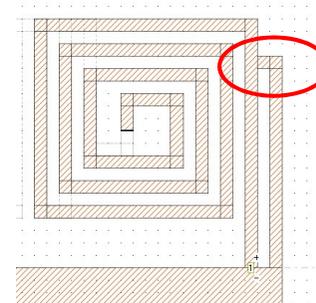
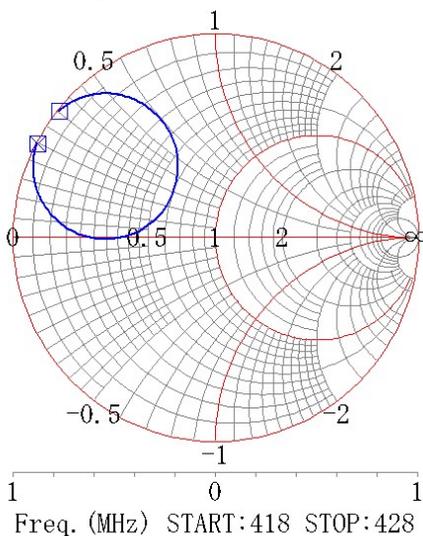
プリントアンテナの整合設計



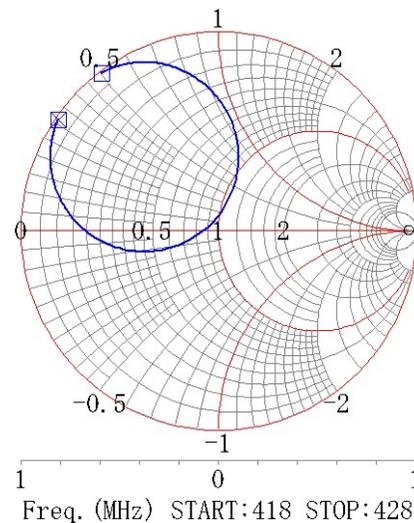
L: S11 □



L: S11 □



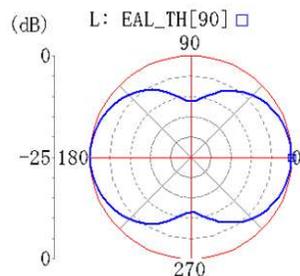
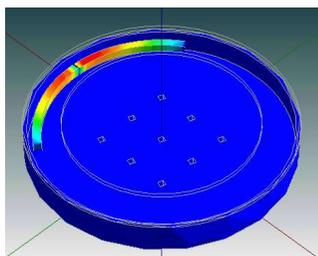
L: S11 □



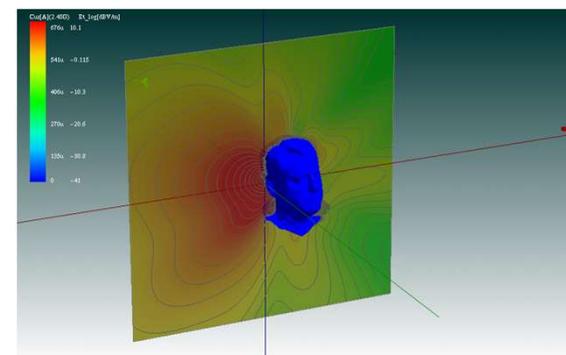
ショートバーなし

人体の影響を解析

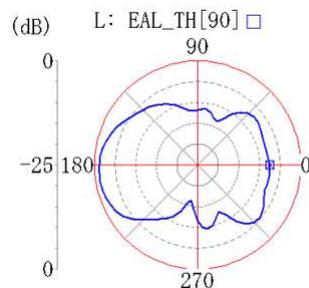
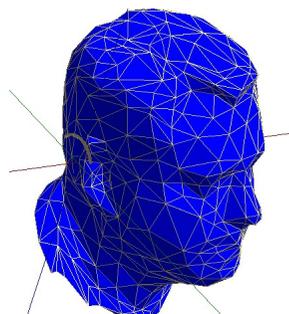
人体の影響を考慮した2.4GHzヘッドホン特性の解析



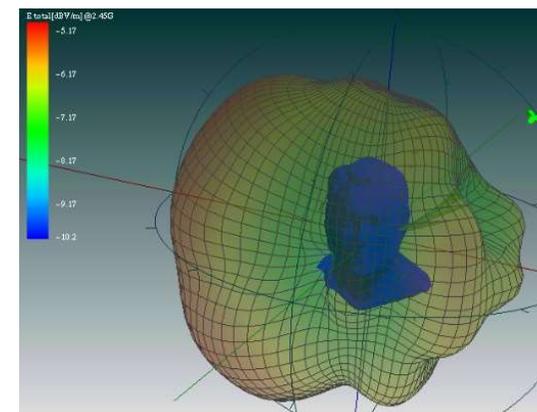
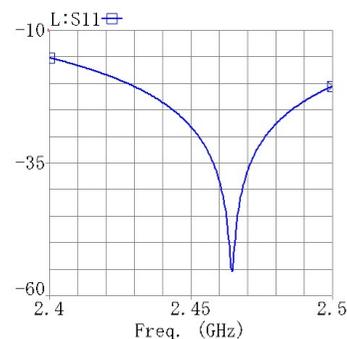
単体の指向性



近傍電界



頭部モデルを含めた指向性



3D指向性

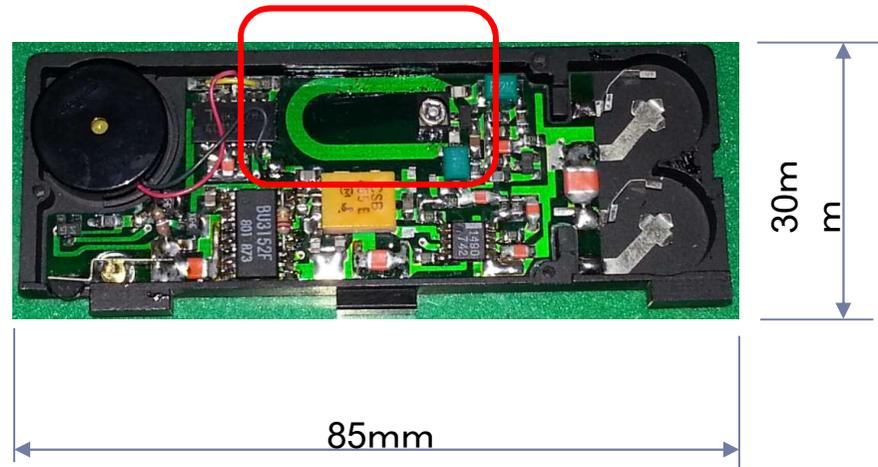
磁界型アンテナ (マグネチックループ)



50MHz



435MHz



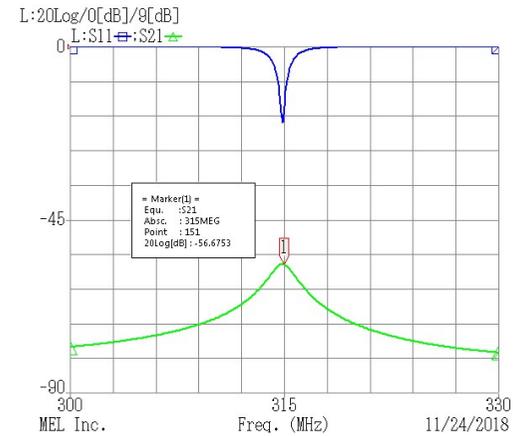
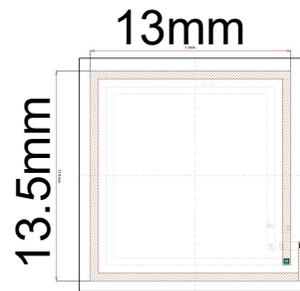
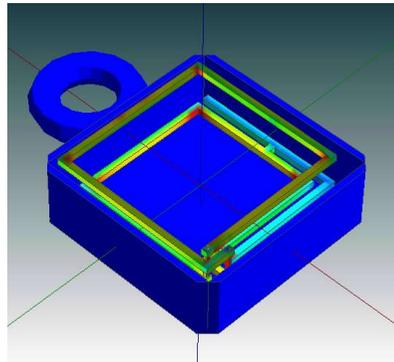
盗難防止タグ用受信器
315MHz
1988年

ループ長 $<\lambda/10$

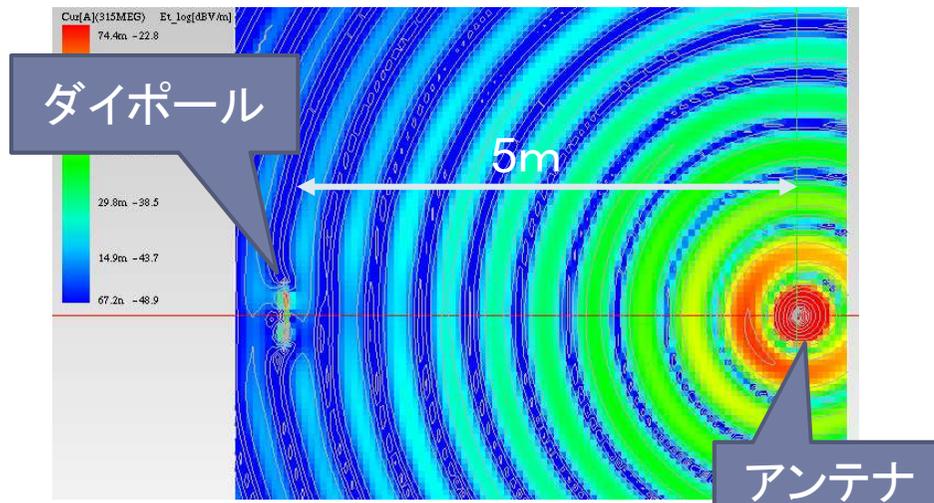


磁界型アンテナ例 (315MHz MLA)

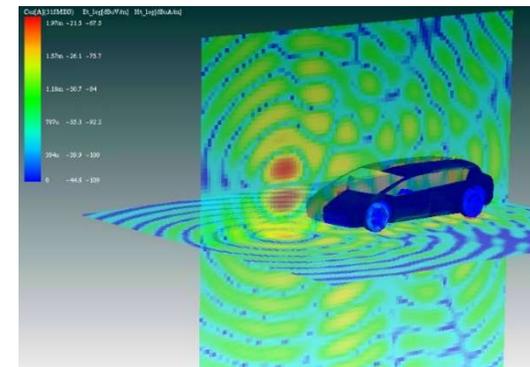
約15mm口の樹脂ケースに入った315MHzのワイヤレスキーのアンテナ設計例



S21=-56.6dB @315MHz

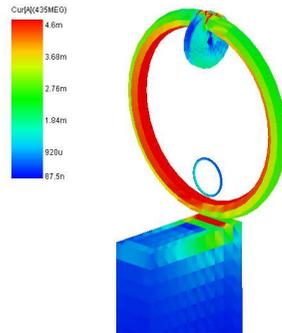
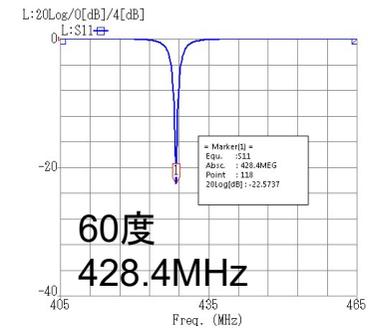
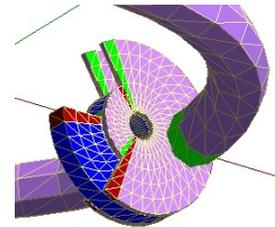
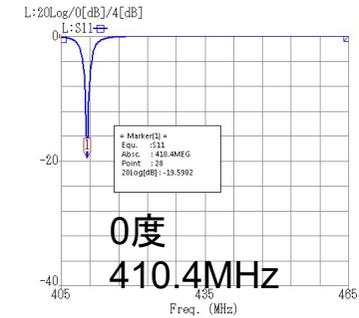
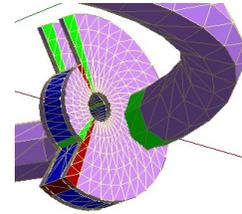
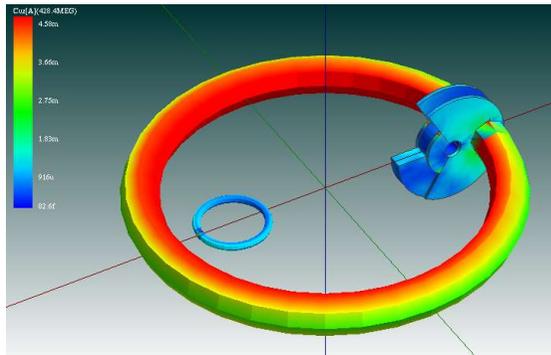


電界分布

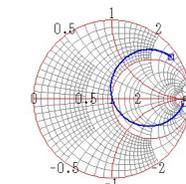
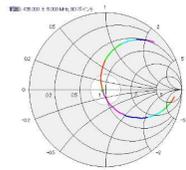


磁界型アンテナ例 (435MHz MLA)

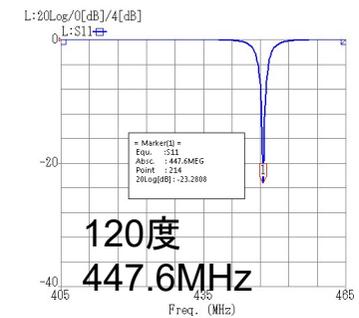
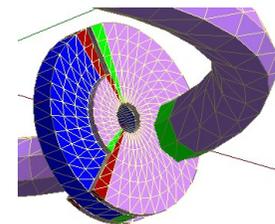
直径 50mm ($\lambda/5$)
誘電体 $\epsilon_r=2.2$ $t=2\text{mm}$



電流密度
分布



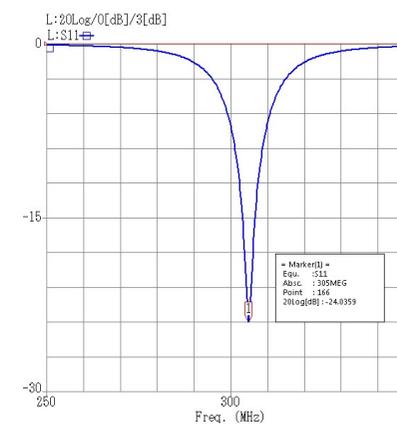
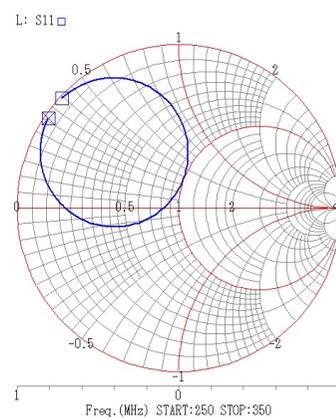
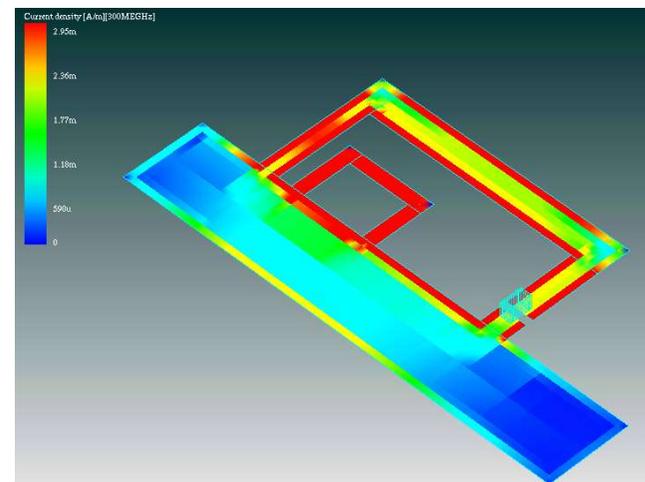
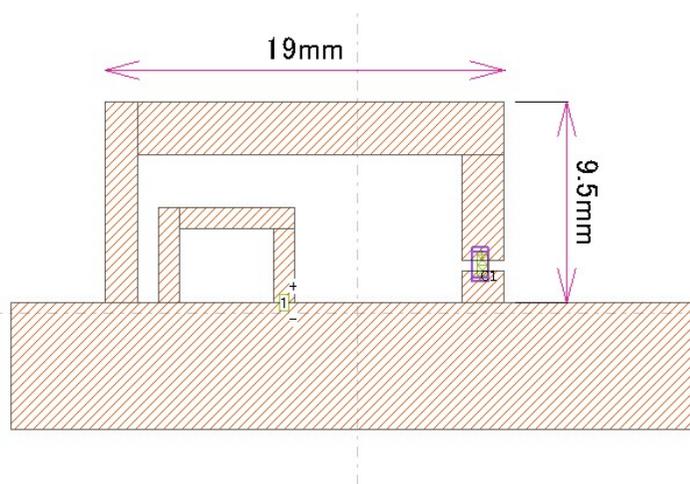
実測(上)とシミュレ
ーション(下)



※435MHz MLA JR10AO 中島氏製作

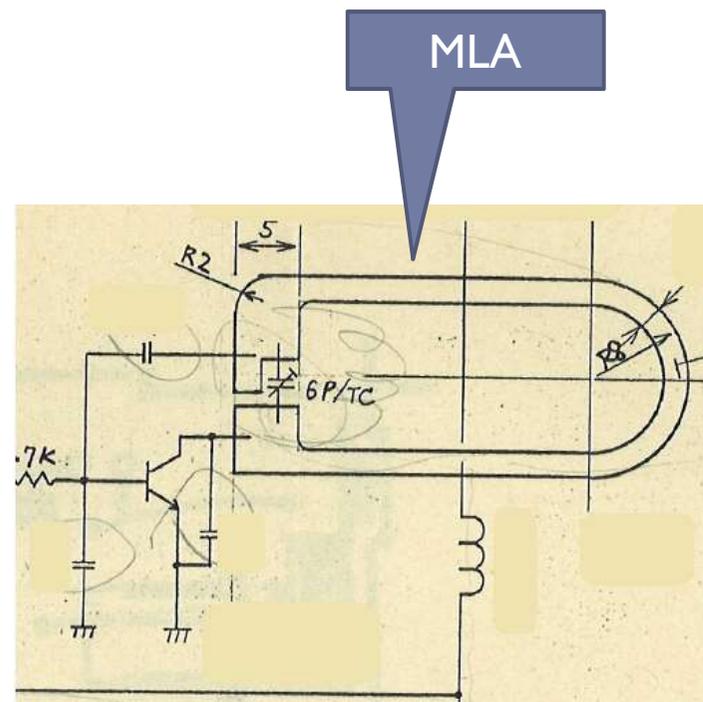
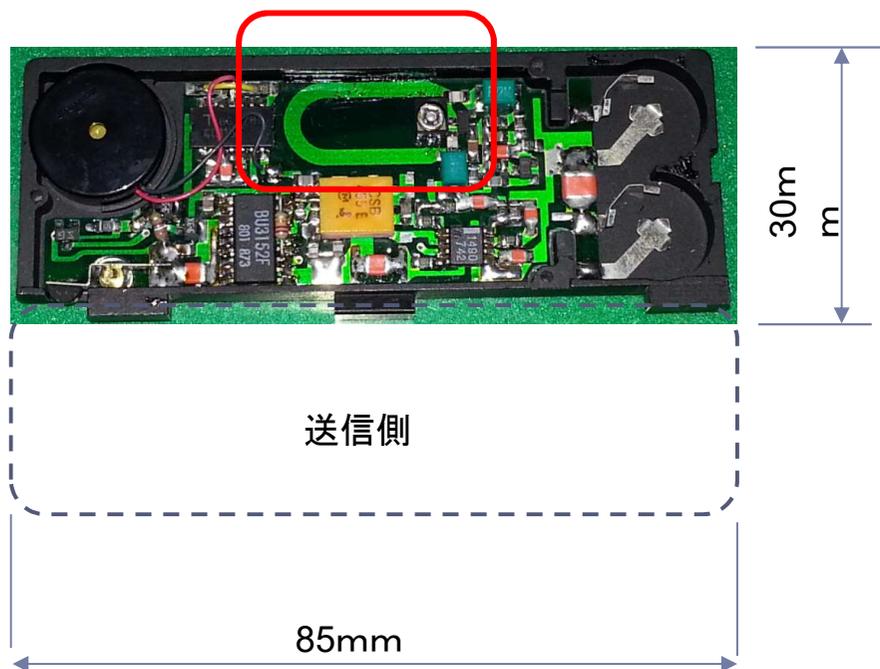
磁界型アンテナ例 (305MHz)

プリント基板上に作成



小型機器への適用例

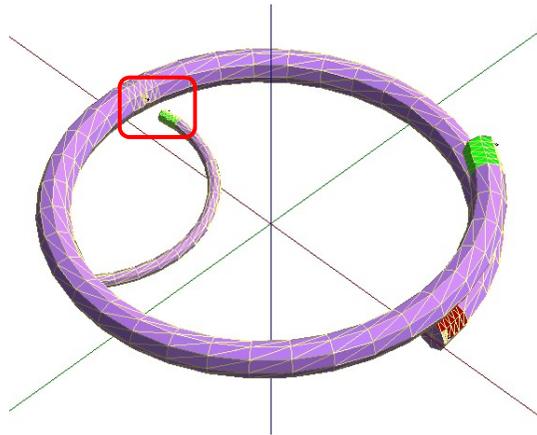
盗難防止タグ用受信器
315MHz
1988年



発振回路(送信側)

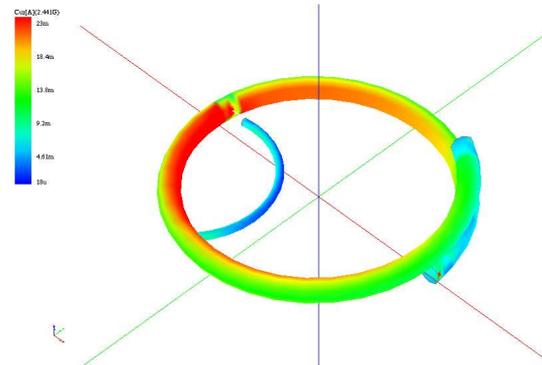
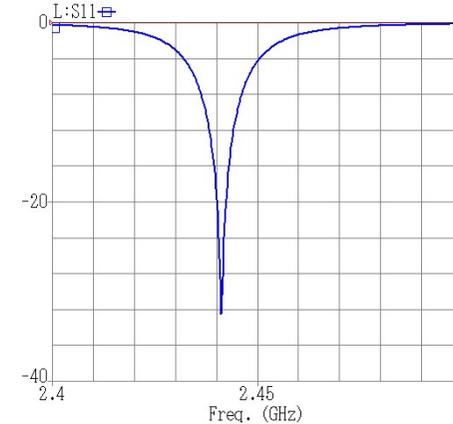
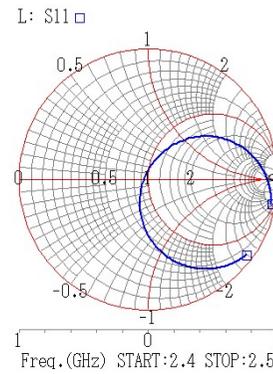
磁界型アンテナ例 (2.45GHz MLA)

ガンママッチによる励振例



D=10mm $\phi=0.8\text{mm}$
巻き数: 1.17T

共振容量は0.17pF程度になる
ので、部分的に重ねて自己共振を用いる方がよい

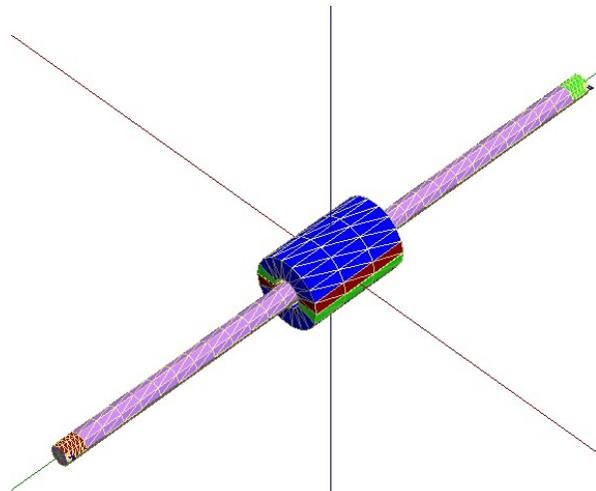


Active port imp.=50
VSWR=1
Direction : $\theta=90, \phi=35$
Sr=0.000481201[W]
Gd=1.7503[dBi]
Ga=0.825668[dBi]
Efficiency=80.8233[%]

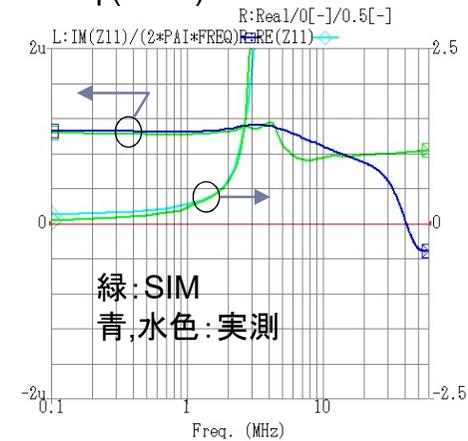
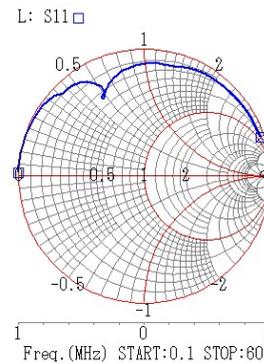
EMC問題への適用

Ur=1000, tanδ=0.4 で100KHz~4MHz帯域でほぼ一致
 解析時間: 20秒/freq, 555秒/301freq (AWE)

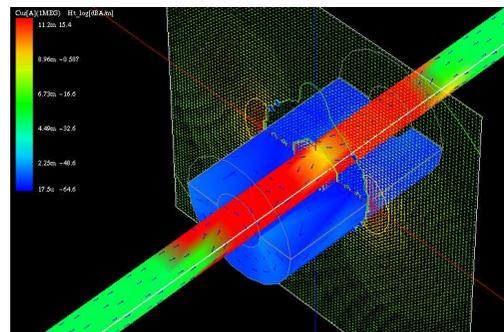
上下のフェライト間隔=0.1mm



材料/属性	
NO=1 Metal	CU, 0.1, False
NO=2 Magnetic	1000, 0.4, 0, *CSV, False
Ur	1000
Td	0.4
Sig	0
File	*CSV
Use file	False

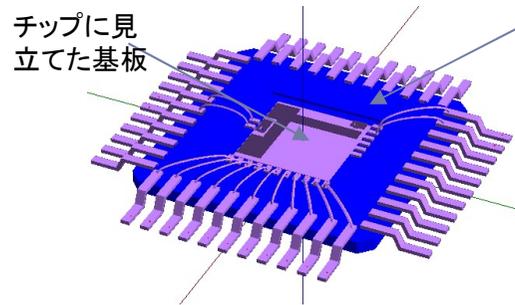


インダクタンスと抵抗

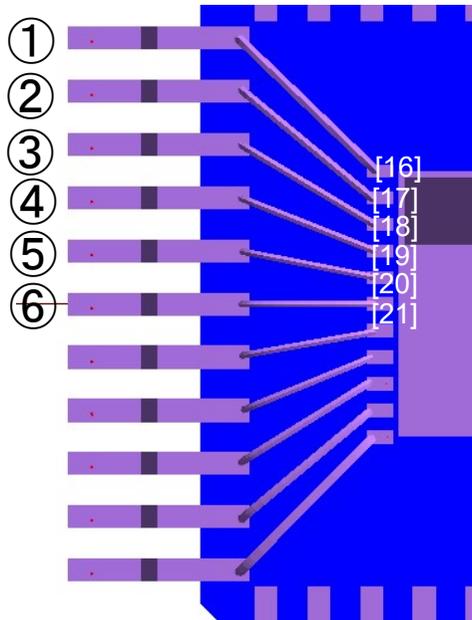
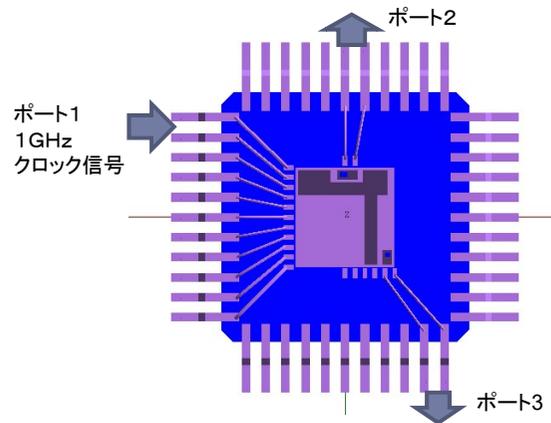


近傍磁界と電流
 コア表面は仮想電流
 @1MHz

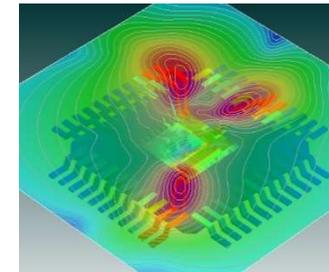
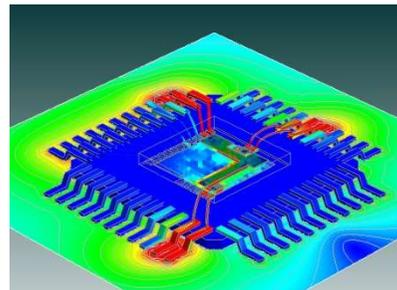
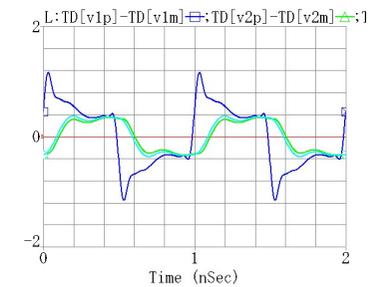
ICパッケージの特性解析



パッケージ ($\epsilon_r=10$)

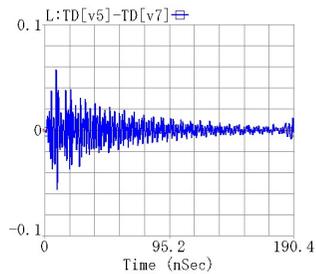
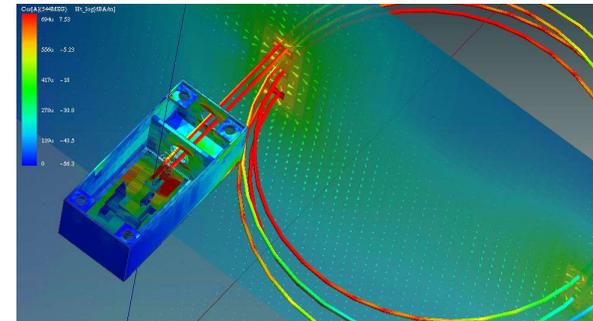
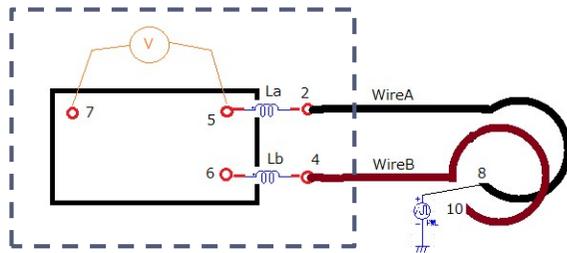
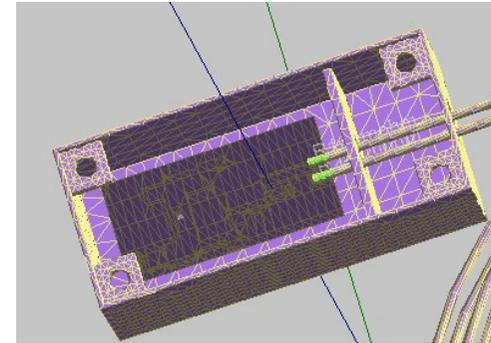
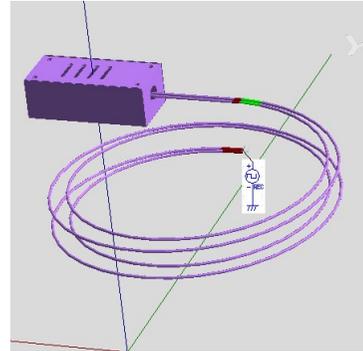


端子	インダクタンス[nH]
①-[16]	3.95
②-[17]	3.76
③-[18]	3.59
④-[19]	3.42
⑤-[20]	3.36
⑥-[21]	3.35

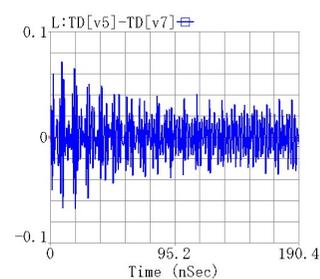


静電ノイズ経路の解析例 (筐体+プリント板+ケーブル)

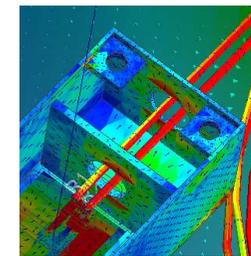
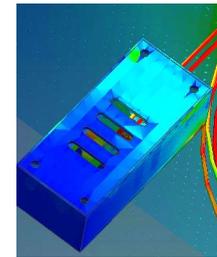
プリント板が内蔵されたケースから約30cmのケーブルが丸められて出ている場合に、ケーブルの先端とグランドの間に静電ノイズを印加した場合の内部のプリント基板上のノイズレベルなどを解析しています。
静電ノイズは8番とFG間に印加され、それが基板内でどれだけのノイズ電圧として現れるかをみています。Lbが大きい場合には基板内のノイズ電圧が大きくなっていることがわかります。



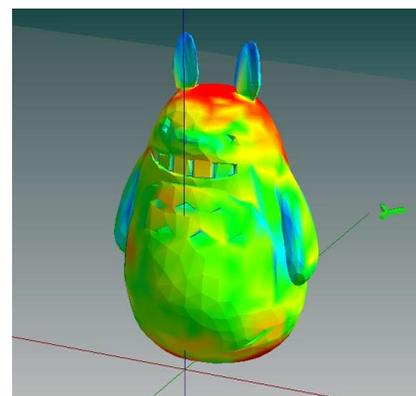
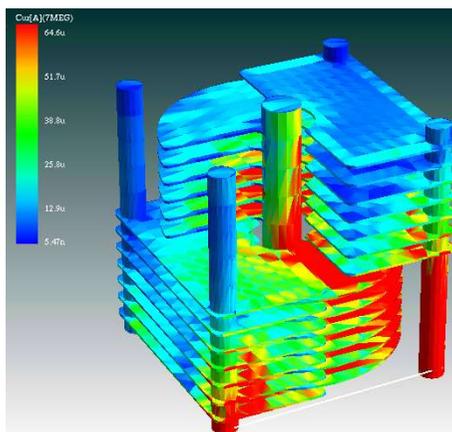
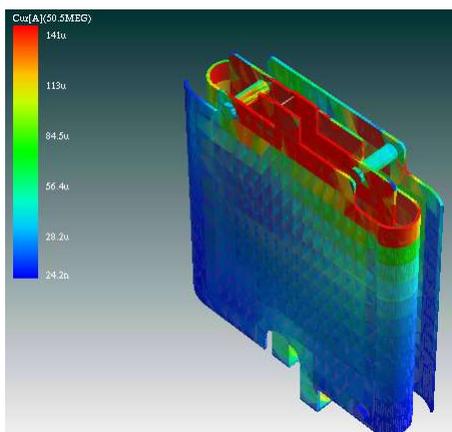
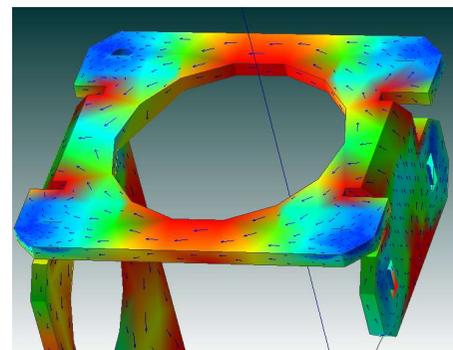
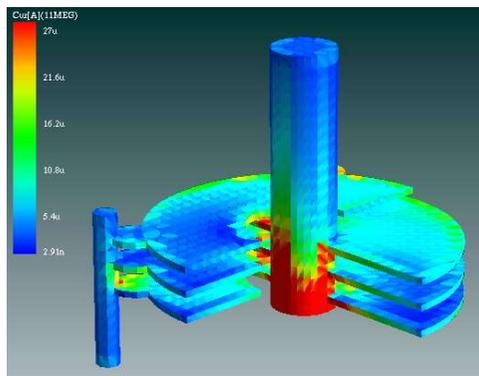
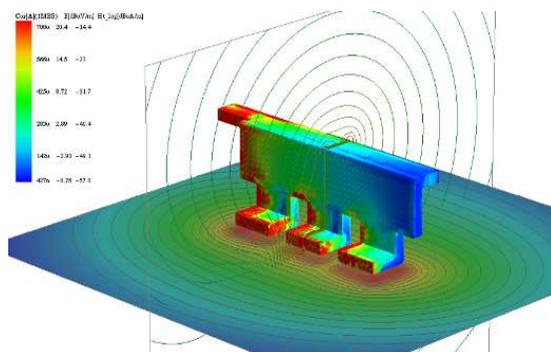
La=Lb=1nH



La=1nH Lb=10nH



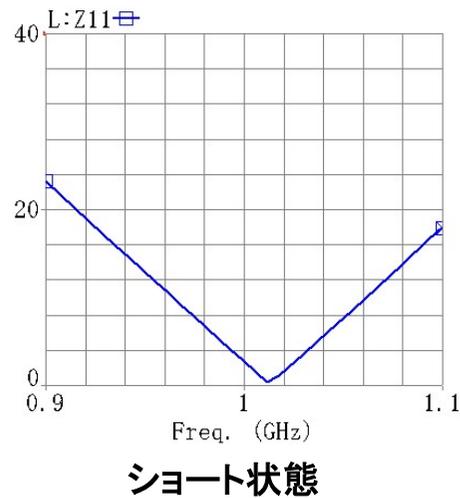
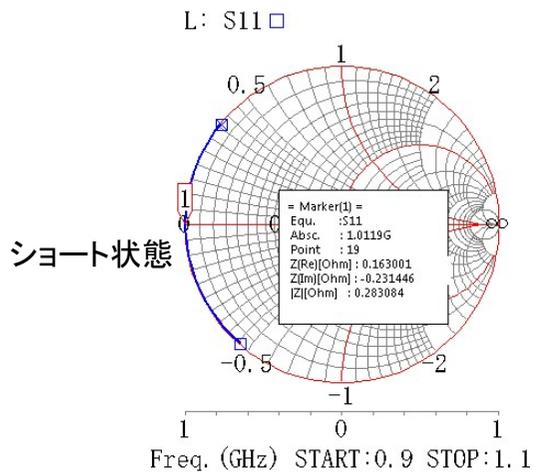
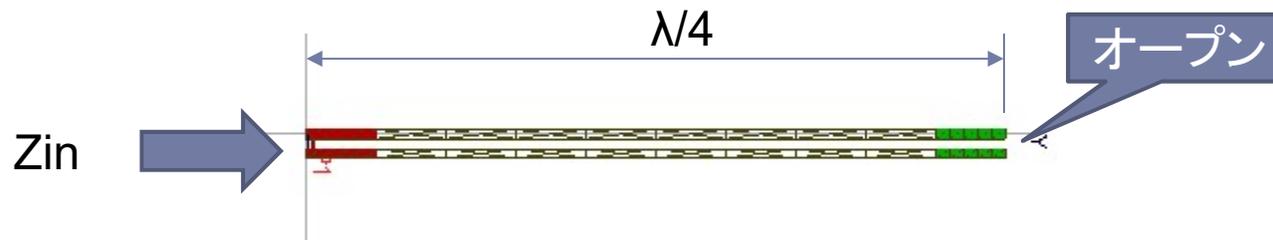
色々な電気部品の解析例



解析時間:48秒/Freq

平行線路

先端開放のλ/4の平行線路の特性

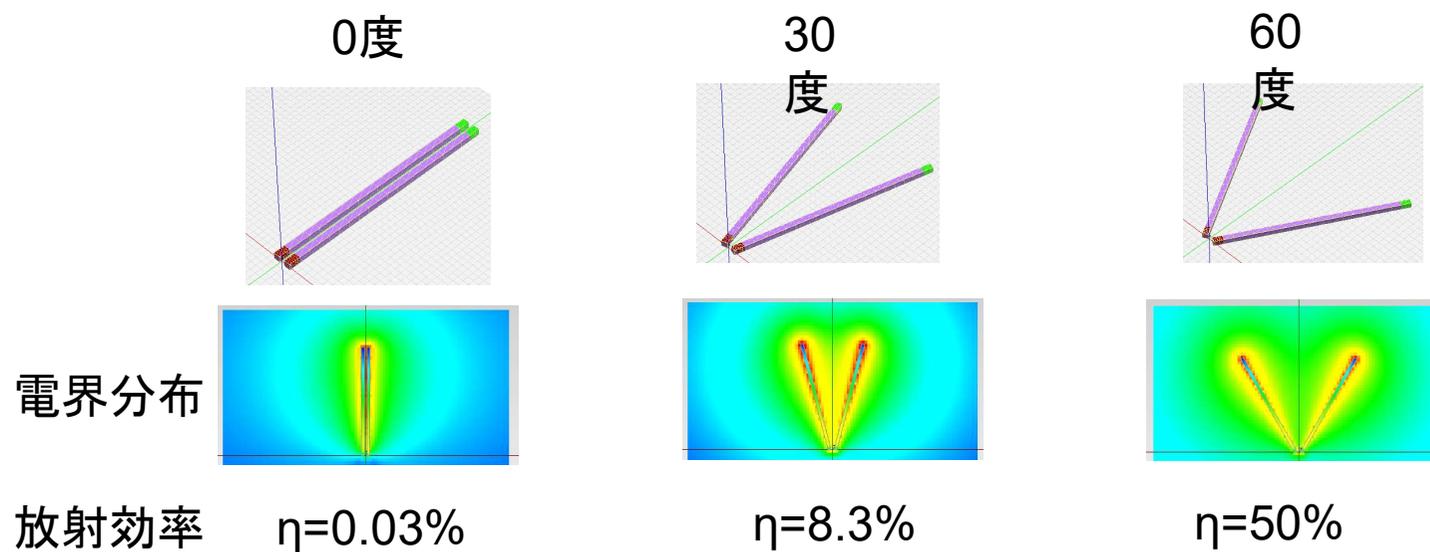


$$Z = Z_0 \frac{Z_r + j Z_0 \tan \beta l}{Z_0 + j Z_r \tan \beta l} \quad \text{--- (7)}$$

長さがλ/4時は、 $\tan \beta l = \infty$ となり
 $Z = Z_0^2 / Z_r$ となる。

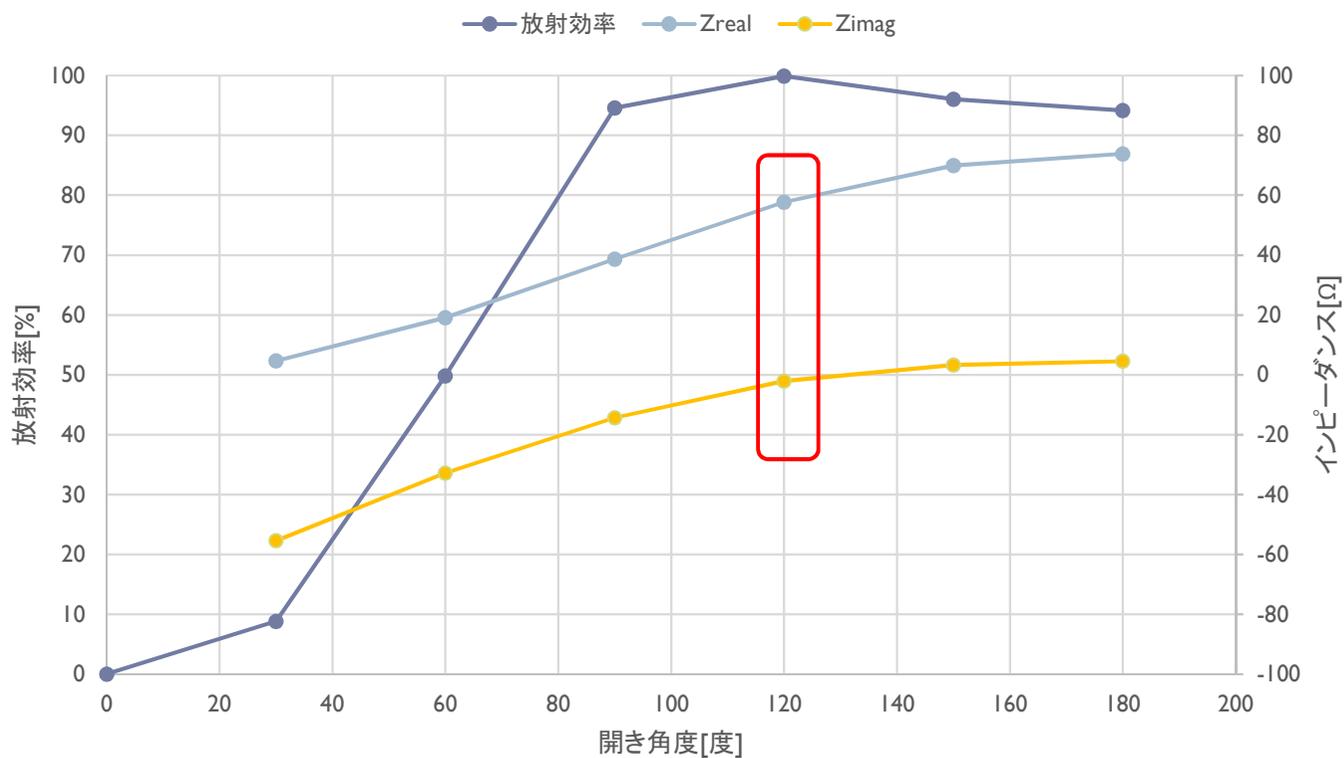
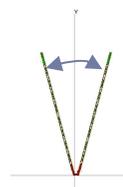
入力インピーダンスは
 負荷インピーダンスに反比例

平行線路の電磁界と放射効率

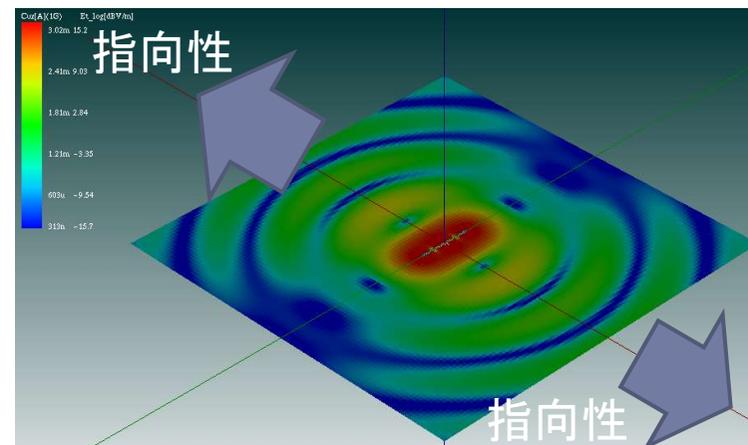
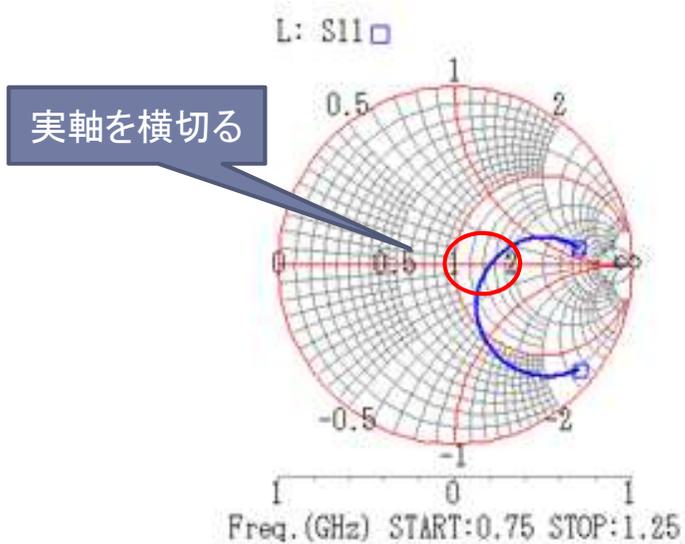


開き角と放射効率

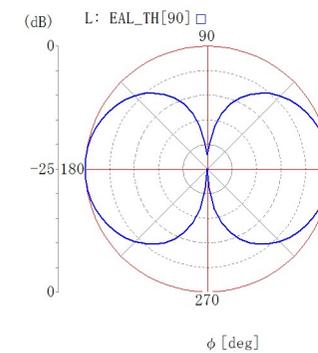
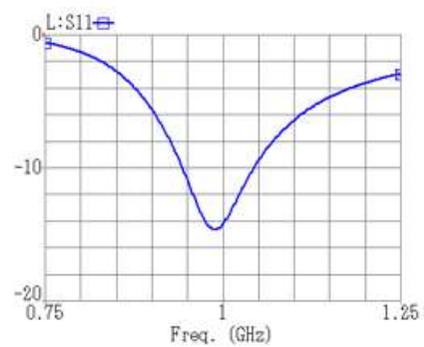
開くにつれて放射効率が大きくなる



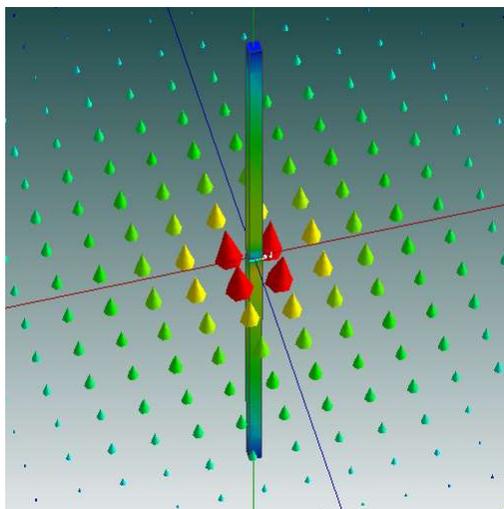
ダイポールの特性



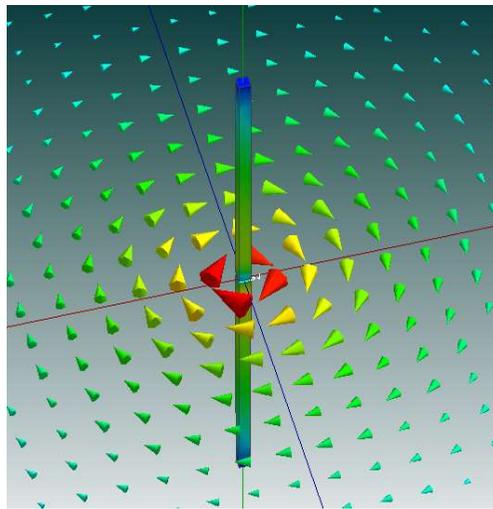
ダイポールのSパラ特性



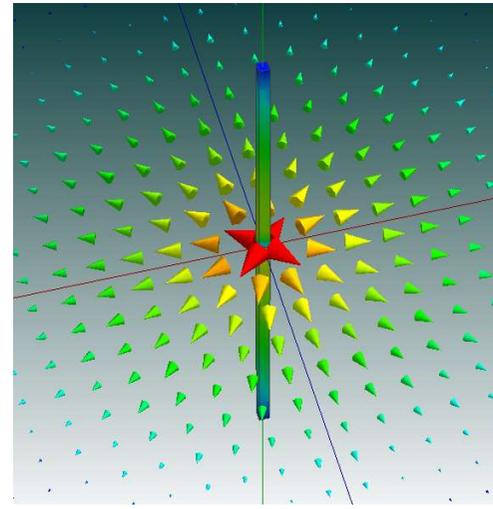
電界・磁界・ポインティングベクトル



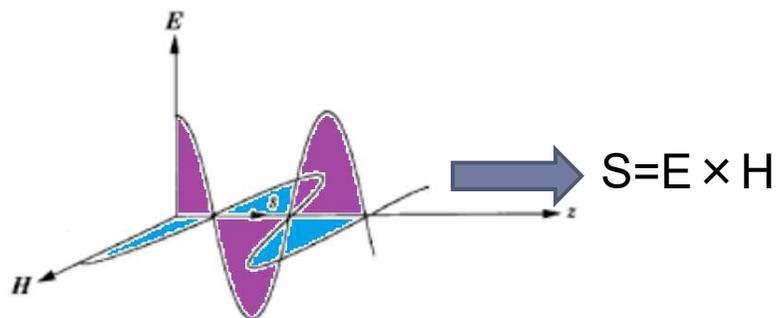
電界
 $E=(E_x,E_y,E_z)$



磁界
 $H=(H_x,H_y,H_z)$



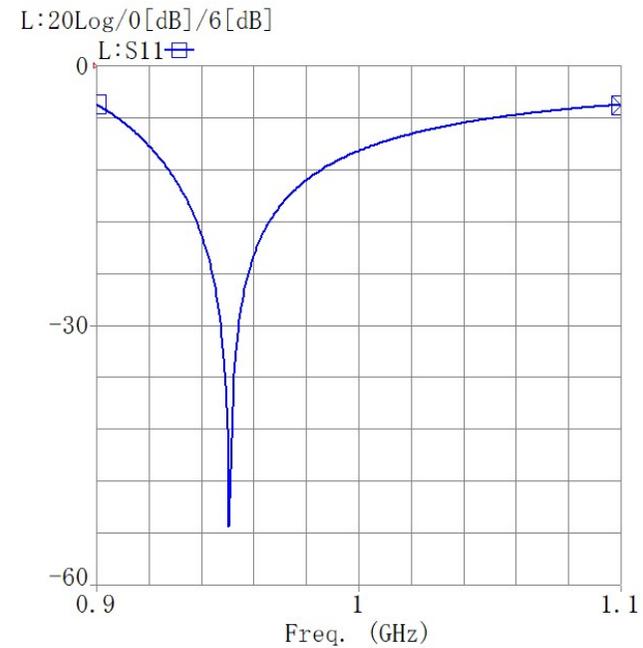
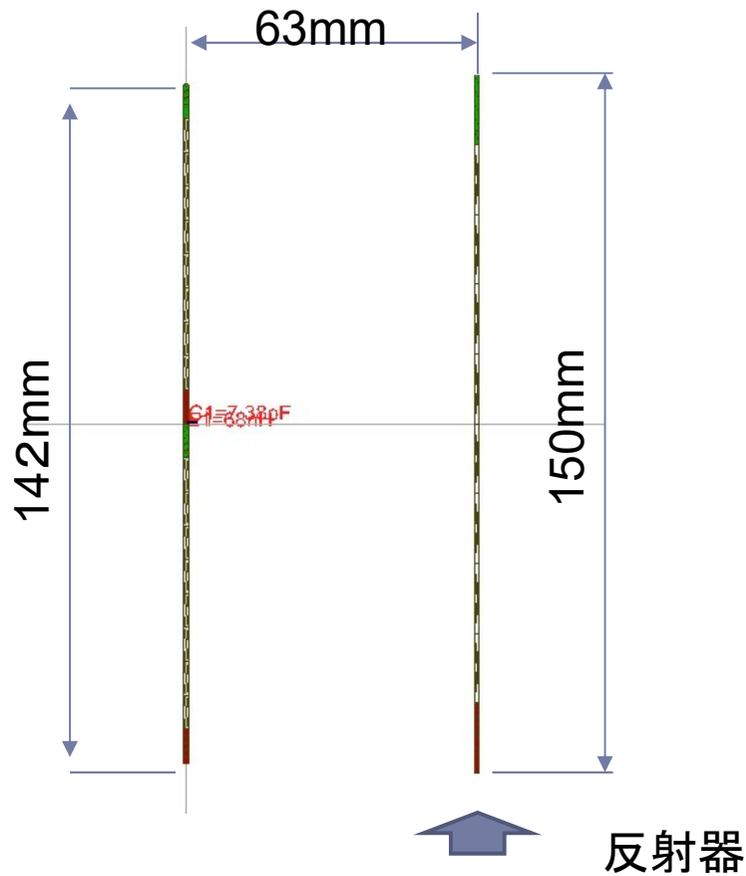
ポインティングベクトル
 $S=E \times H$



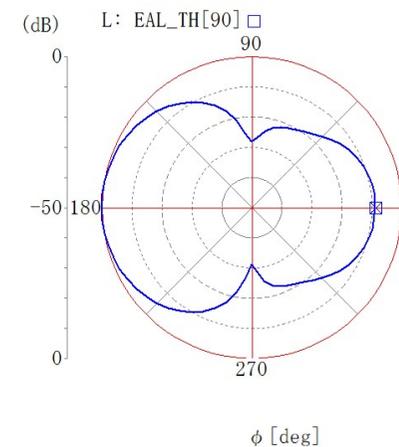
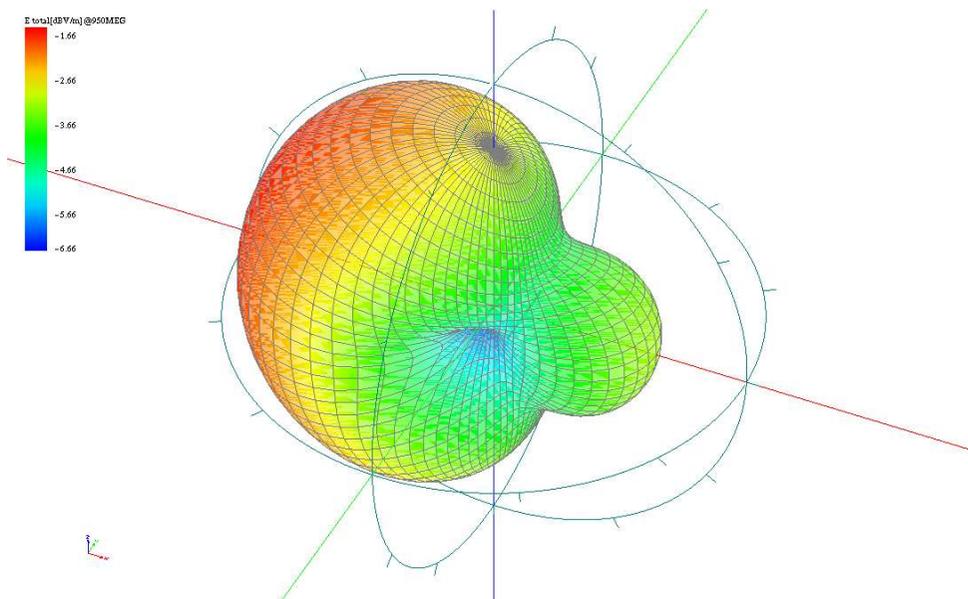
八木アンテナ (2エレメント)

演習

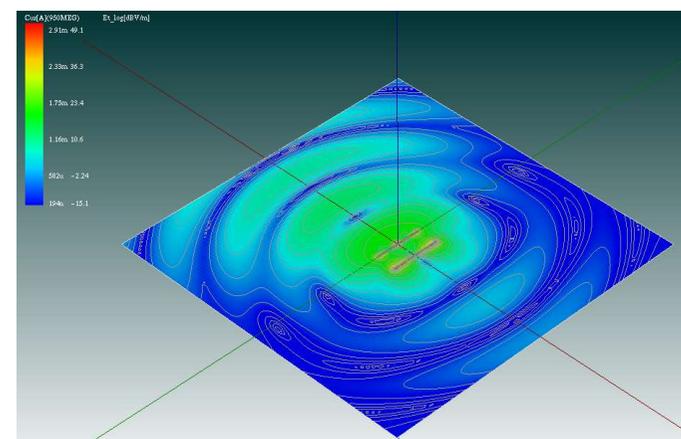
- ・ダイポールアンテナの後ろに反射器を設置 ($\approx \lambda/4$)



八木アンテナ (2エレ) 指向性



放射効率と指向性利得
Direction : th=90,phi=180
Sr=0.00181114[W]
Gd=6.53366[dBi]
Ga=6.58191[dBi]



まとめ

- ▶ 電磁界解析手法の概要を紹介。
- ▶ 特長1:遠方間の特性解析を紹介。
- ▶ 特長2:超低周波からの解析。
- ▶ 電界型磁界型小型アンテナの紹介
- ▶ 筐体を含めた解析の紹介
- ▶ EMC問題への適用の紹介
- ▶ アンテナの成り立ち